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HOSPITAL TECHNICAL MEMORANDUM

ABATEMENT OF ELECTRICAL INTERFERENCE

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MINISTRY OF HEALTH HOSPITAL TECHNICAL MEMORANDUM NO. 14

Abatement of Electrical Interference

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I. Scope

1. This Technical Memorandum is intended to assist:

(i) Manufacturers and others who are concerned with the design of sensitive electro-medical equipment.

(ii) Medical and other staff who are concerned with the satisfactory functioning of sensitive electro-medical apparatus.

(iii) Engineers who are responsible for the design and installation of electrical systems and equipment which may be a source of electrical interference to electro-medical apparatus.

(iv) Architects and others who are responsible for the layout and planning of accommodation in hospitals.

II. Introduction

2. Hitherto, possibly because of limited knowledge of the methods for the avoidance and suppression of electrical interference, new equipment, electrical installations and layouts of hospitals have not been designed with this in view.

3. Statutory Regulations and British Standards Institution publications dealing with interference have been primarily concerned with preventing various types of equipment (including electro-medical apparatus) from interfering with radio services, rather than protecting sensitive apparatus such as is being increasingly used in hospitals, against interference from other sources.

4. Sensitive equipment in hospitals is liable to suffer three distinct types of electrical interference, namely from electro-magnetic fields (radio waves), alternating magnetic fields, and from alternating electrostatic fields. Each type of interference requires a different method of suppression.

5. Interference suppression in hospitals has been largely confined to electrical screening of rooms in which sensitive apparatus is used. The provision of screened rooms is costly and makes for inflexibility in the planning and layout of departments. Furthermore, this method of protection cannot be used for portable apparatus which is being increasingly used in wards and in other parts of the hospital.

6. The advice given in this Memorandum is based on research and experimental work which has been carried out to determine the main causes of interference in hospitals and to establish the simplest and most appropriate means of preventing the interference.

7. Investigations have shown that filter components incorporated in the input circuits of sensitive apparatus can satisfactorily reject most radio frequency interference signals and that sufficient physical separation will usually eliminate interference due to electrostatic or magnetic fields. Physical separation will, of course, also assist in reducing r.f. interference. Tests have shown that a number of existing screened rooms are largely ineffective due to deficiencies in construction.

III. Sources of interference

8. Sources of interference may be divided into the following main categories:

(i) Electro-magnetic radiation (radio waves) from equipment within the hospital, e.g. diathermy apparatus, which incorporate a high frequency generator for functional purposes. The interference is largely due to low frequency modulation of the high frequency carrier, causing low frequency signals to be superimposed on wanted physiological measurements. Detection of the low frequency modulation can occur at any non-linear component (valve or transistor) within sensitive electro-medical equipment and the interference signals may be amplified in the subsequent stages of the equipment together with the wanted signals. In addition to direct radiation, there is the possibility of interference signals being fed into mains wiring via the mains connection to the high frequency generator and so reach sensitive equipment connected to the mains. Signals may also be induced into the mains wiring in areas of high field strength and be conducted throughout the building by the mains network. Signals may similarly be picked up by other installed engineering services, constructional metal work, etc., and re-radiated in other parts of the building.

(ii) Electro-magnetic radiation and/or transient current surges on the mains from equipment incorporating switches, commutators, etc., or other means of interrupting electrical circuits.

(iii) Alternating magnetic fields such as are

generated by transformers or when phase and neutral conductors of an alternating current circuit are not installed in close proximity, e.g. where the line conductor of a circuit is run down one side of a room and the neutral conductor down the other or where the phase lines of a three phase circuit are run separately. Alternating magnetic fields are also generated by stray earth currents in water pipes where they form parallel leakage paths to earth due to a load being connected between line and earth or to a neutral conductor being earthed locally. Similar fields are intentionally created by inductive loop, staff location systems.

(iv) Alternating electrostatic fields, due to the presence of unscreened conductors carrying alternating potentials (e.g. wiring at mains potential).

(v) Electro-magnetic radiation from sources outside the hospital, e.g. from high powered radio or television transmitters or local mobile transmitters such as those used by ambulances, police, taxis, etc. Sound broadcasts are less likely to cause trouble as the modulation frequencies are above the maximum frequency to which pen recorders can respond, but interference from these sources may be detected by apparatus employing oscilloscopes. Television broadcasts incorporate a 50 c/s (frame) signal which can cause interference in areas where strong signals are received, e.g. in excess of 100 millivolts per metre.

9. Electrostatic floors can cause persons to become charged to high potentials and interference can be caused by electrostatically charged persons walking or moving about near patients whilst biological measurements are being made. Highly electrostatic materials on or near the couch or bed can produce similar interference.

10. Radio frequency sources can radiate over wide areas and this type of interference is likely to be the most troublesome. Electrostatic and magnetic interference is usually confined to a comparatively small area surrounding the source.

11. "Transients", e.g. due to switching, are liable to occur frequently on any mains distribution system and in some instances peaks up to 400 volts may be experienced.

IV. Equipment liable to cause interference

12. The following types of equipment are liable to cause interference:

(i) Medical (therapeutic) diathermy

(ii) Surgical diatheramy

(iii) Staff location systems (inductive loop and v.h.f.)

(iv) Linear accelerators and other therapeutic x-ray generators

(v) Lifts, including motors and control equipment

(vi) Electrically heated appliances incorporating thermostatic controls including ovens, sterilisers, incubators, blankets, refrigerators, food trolleys, etc.

(vii) Switches, relays, contactors and similar control devices which interrupt circuits

(viii) Transformer sub-stations and other power transformers

(ix) Electric clocks (impulse and synchronous (mains) types)

(x) Fluorescent lamps, including cold cathode types

(xi) Radio communication equipment

(xii) Motor operated equipment including vacuum cleaners, floor polishers and other domestic equipment

(xiii) Highly electrostatic materials in the proximity of the patient, e.g. vinyl and other highly electrostatic floors and items on the couch or bed, such as plastic mattress or couch covers and draw sheets and woollen blankets. (Anti-static precautions are dealt with in Hospital Technical Memoranda Nos. 1 and 2.)

V. Detection and measurement of interference

13. Radiated interference signals are usually expressed in terms of the field strength and measured as a voltage induced in an aerial having an effective height of one metre. For assessing interference radiation from a specific source, measurements are made at 10 or 30 metres distance. Noise voltages induced into the supply mains from a source of interference are expressed in microvolts. Specially calibrated radio receivers are used for measuring field strength and noise voltages.

14. Comparatively simple equipment will determine whether interference is due to magnetic, electrostatic or radio frequency fields. Details of such equipment are given in Appendix I.

VI. Statutory limits for radio frequency interference

15. In order to protect radio services, internationally agreed Statutory Limits are laid down for the field strength of radio frequency interfering signals and terminal noise voltages. Special frequencies, however, are allocated for industrial, scientific and medical purposes (I.S.M. frequencies) and unlimited radiation is permitted on these frequencies. In the special case of surgical diathermy there is no restriction on either frequency or power.

16. The interference limits specified in the Wireless Telegraphy (Control of Interference from Electro-Medical Apparatus) Regulations 1963 are as follows:

Frequency range	Max. field strength in microvolts per metre at 30 metres	Max. mains terminal voltage in microvolts
150 kc/s–40 Mc/s (excluding I.S.M. frequencies)	30	1,500
40 Mc/s–118 Mc/s	15	750
118 Mc/s–223 Mc/s	30	1,500
13·56 Mc/s ± 0·05% (I.S.M. frequency)	unlimited	unlimited
27·12 Mc/s ± 0·6% (I.S.M. frequency)	unlimited	unlimited

17. Limits for the field strength and terminal voltage of harmonics of 13·56 Mc/s are also laid down.

18. Somewhat similar limits, but over a restricted frequency range, are specified in Statutory Instruments Nos. 291 (electric motors) and 292 (refrigerators). B.S.800 (limits of radio interference) also makes recommendations based on similar limits.

19. In general, the interference limitations imposed by the Statutory Instruments represent a higher standard of interference suppression than is necessary to protect sensitive apparatus in hospitals. It is the unrestricted radiations on the I.S.M. frequencies and from surgical diathermy which constitute the main sources of radio frequency interference in hospitals.

VII. Interference suppression: electro-medical apparatus

20. If the clinician or research worker is to obtain a true indication of the electrical potentials he is studying, extraneous signals within the appropriate band width must be reduced to a value less than the smallest signal he wishes to consider.

Apparatus most liable to be affected

21. Apparatus which is most likely to suffer interference will be that concerned with the measurement or indication of low frequency physiological potentials, e.g. at frequencies up to 20 kc/s. The use of sensitive display equipment, e.g. that used in radiology, is on the increase and this is also liable to suffer interference from extraneous signals.

22. The following are examples of apparatus which may be affected:

Electro-myographs (E.M.G).

Electro-encephalographs (E.E.G.).

Electro-cardiographs (E.C.G.).

Radio-active pulse measuring apparatus

Image intensifiers

Closed-circuit television

23. Hearing aids employing a magnetic microphone (e.g. Medresco OL 56) are liable to suffer interference from low frequency, inductive loop, staff location systems and from stray magnetic fields. Those employing crystal microphones (e.g. Medresco OL 35 A) are less liable to suffer interference from alternating magnetic fields.

Methods of rejection for sensitive apparatus

24. The chief methods of suppressing electrical interference in electro-medical apparatus are:

(i) Siting potential interference generating sources away from areas where sensitive equipment may be used.

(ii) Incorporating in-phase rejection in the early amplification stages.

(iii) Provision of filter components in the input (patient) circuits.

(iv) Fitting of suppression components in the mains input circuits.

(v) Provision of earthed metal enclosures for sensitive equipment and screening associated wiring connections.

(vi) Keeping patient leads as close together as possible to minimise interference due to magnetic fields.

In-phase rejection

25. Arrangements for rejecting unwanted in-phase signals, e.g. those at mains frequency, are usually incorporated by manufacturers of the apparatus, by the use, for example, of carefully balanced (differential) amplifiers. With suitable arrangements very high rejection ratios are obtainable and such

measures form a very effective means of reducing low frequency electrostatic interference.

Filters

26. The filtering of wanted low frequency signals from unwanted radio frequency signals is a most effective method of preventing interference from radiated sources. Tests have shown that E.E.G. and E.C.G. can be operated successfully in the presence of radio frequency fields of up to 1 volt/metre when a suitable low pass filter is incorporated. Since wanted signals are at comparatively low frequencies it is an easy matter to filter these from unwanted radio frequency signals. Resistors and capacitors for this purpose are available in very small sizes and they can usually be incorporated into the apparatus without difficulty.

27. It is important that filter components do not adversely affect the proper functioning of apparatus and the added capacitance must not adversely affect the response at the upper end of the required frequency band. In most instances it has been found that the small additional capacitance necessary to give satisfactory results is acceptable. Where additional capacitance cannot be tolerated, e.g. E.M.G. apparatus, a grid stopper in conjunction with the inter-electrode capacitance of the first valve, and without additional capacitance, may be satisfactory. An alternative is to use a 50 or 100 c/s band stop filter in a subsequent stage of the apparatus.

Low pass filters

28. For optimum results filter components should be located as close as possible to the first non-linear component, i.e. valve, transistor or diode. Where such an arrangement is not convenient, acceptable results may be obtained where the filter components are located close to the input terminals. All parts of the circuit subsequent to the filter should be completely screened with earthed metal.

29. A single section low pass filter will be satisfactory in most instances but where the highest degree of rejection is required, additional sections will be necessary.

30. Where two or more sections are used the first sections will usually be at the input terminals and the last section at the first stage of amplification. Part of the input capacitance will be formed by the screened cable in the input circuit and this may amount to 300 p.F. In the normal multi-core screened cable the capacitance of each conductor to earth will depend on the position of the conductor relative to the outer screening. Where the highest degree of rejection is required any deficiency due to this can be overcome by using miniature coaxial cables for the core conductors and bonding the screen of each conductor to the earth continuity system at the terminations.

31. Figure 1 shows the response curves of typical low pass filters which would be suitable for use in high impedance circuits, and Figures 2–5 show typical applications of low pass filters in physiological amplifiers.

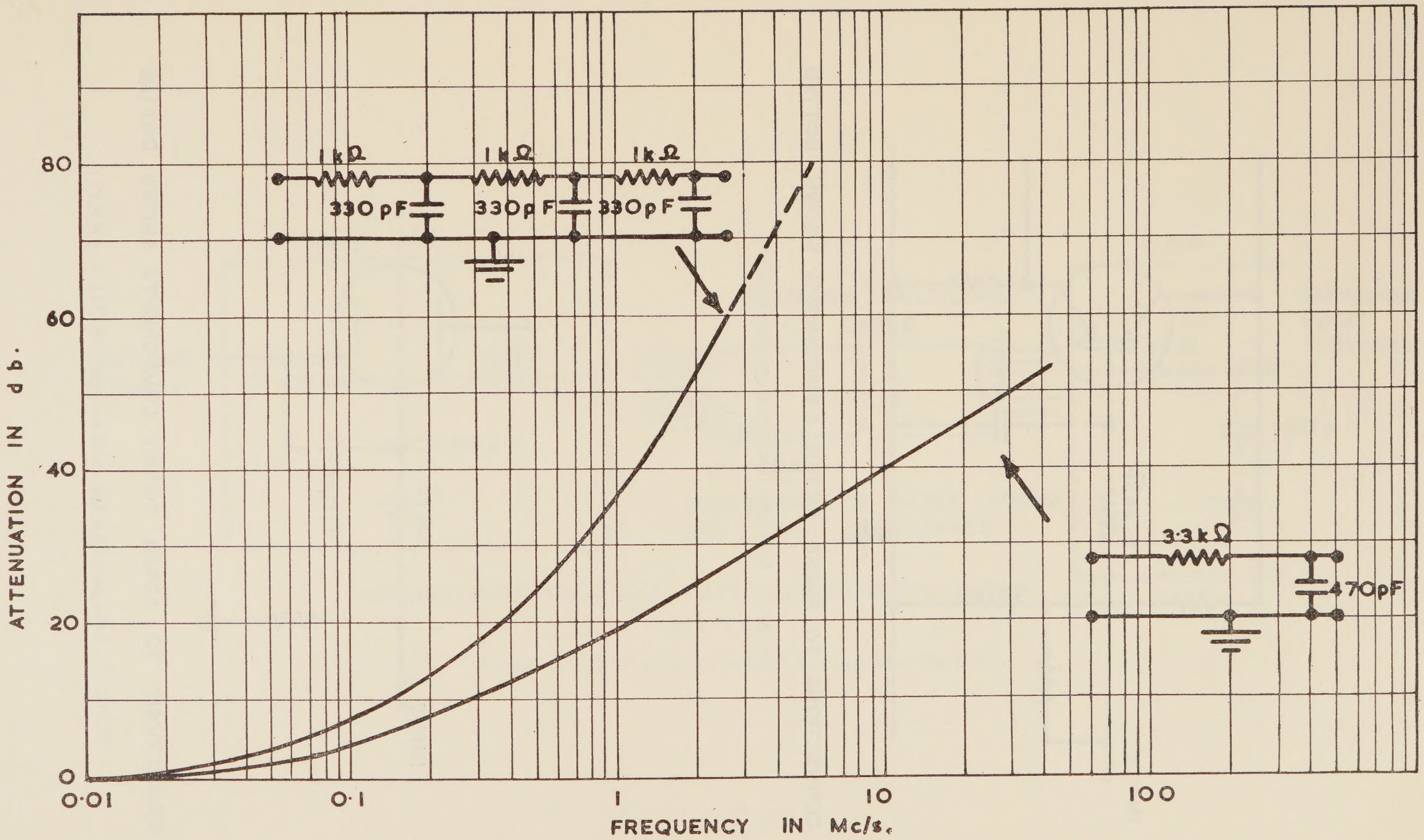


FIGURE 1. Response curves of typical low pass filters for high impedance amplifiers

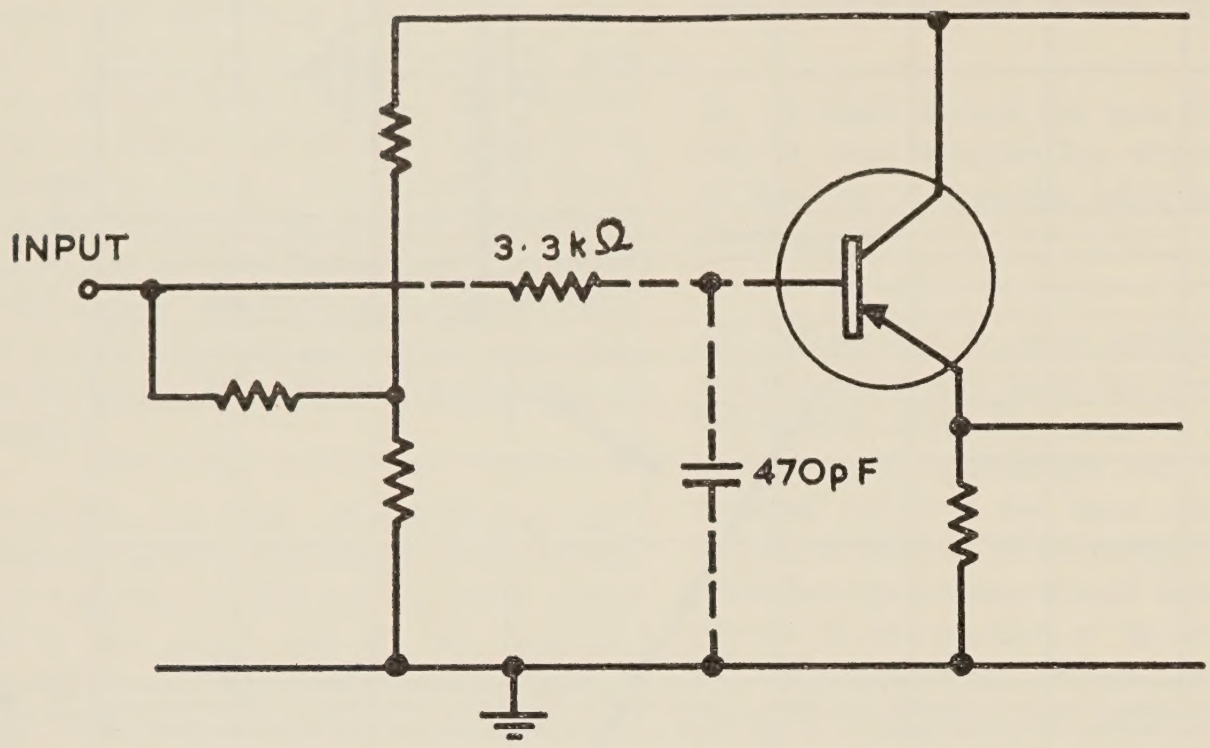


FIGURE 2. Low pass filter for transistor amplifier

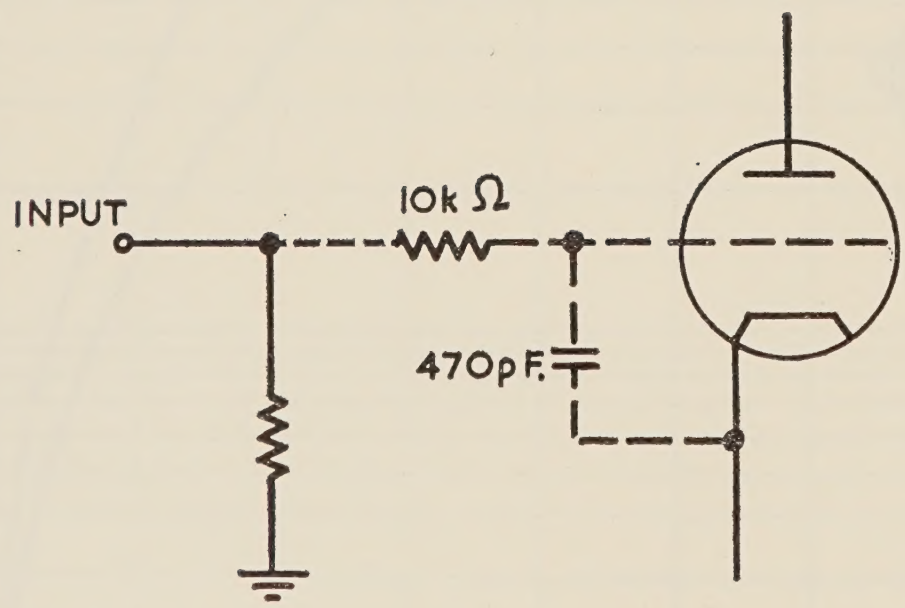


FIGURE 3. Low pass filter for valve amplifier (E.C.G. and E.E.G.)

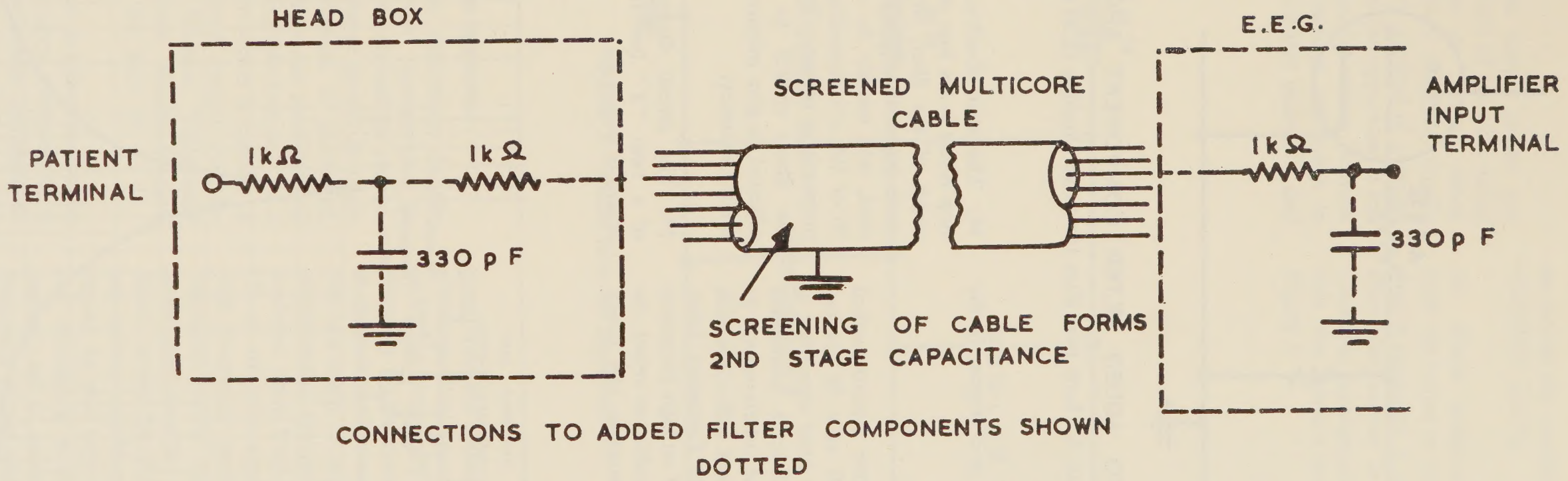


FIGURE 4. Three section " ladder " low pass filter for E.E.G.

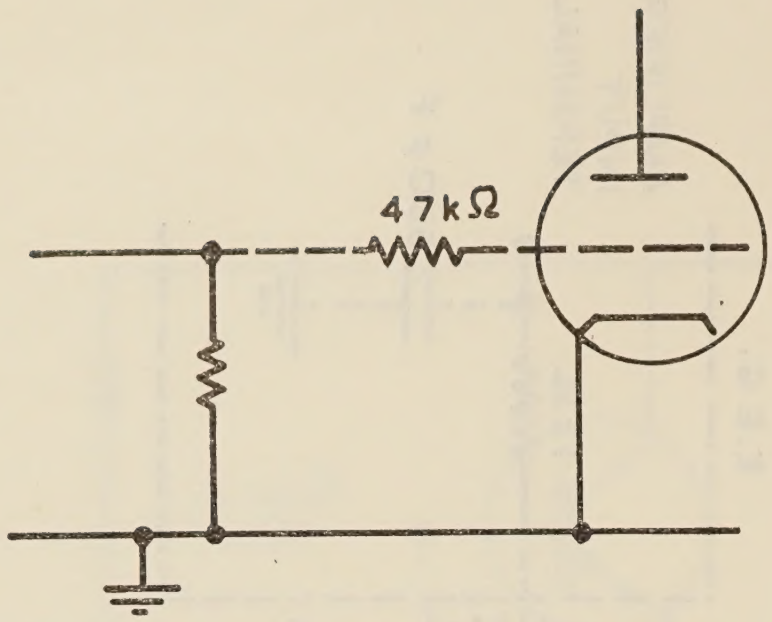


FIGURE 5. Low pass filter for valve amplifier (E.M.G.).

32. Figure 5 shows the use of a grid stopper in the pre-amplifier of an E.M.G.

Low frequency band stop filters

33. Since interference to sensitive electro-medical equipment usually manifests itself as a 50 c/s unwanted signal an effective narrow band stop filter at the interfering frequency would be a convenient means of eliminating this type of interference. In practice, however, there are inherent difficulties with low frequency filters and, as low frequency interference signals are mostly radiated on high frequency carriers, it will usually be preferable to reject the high frequency signals before detection can occur.

34. The main disadvantage of low frequency band stop filters is the loss of information over the bandwidth of the filter, which may be significant with some types of apparatus. Band stop filters, where used, will usually be required to reject signals at 50 or 100 c/s depending on the arrangement of the propagating source. To obtain maximum rejection the filters should be adjustable and should be adjusted to give minimum attenuation at the appropriate frequency.

35. The circuit diagram and performance curve of a twin "T" low frequency band stop filter is shown in Figure 6.

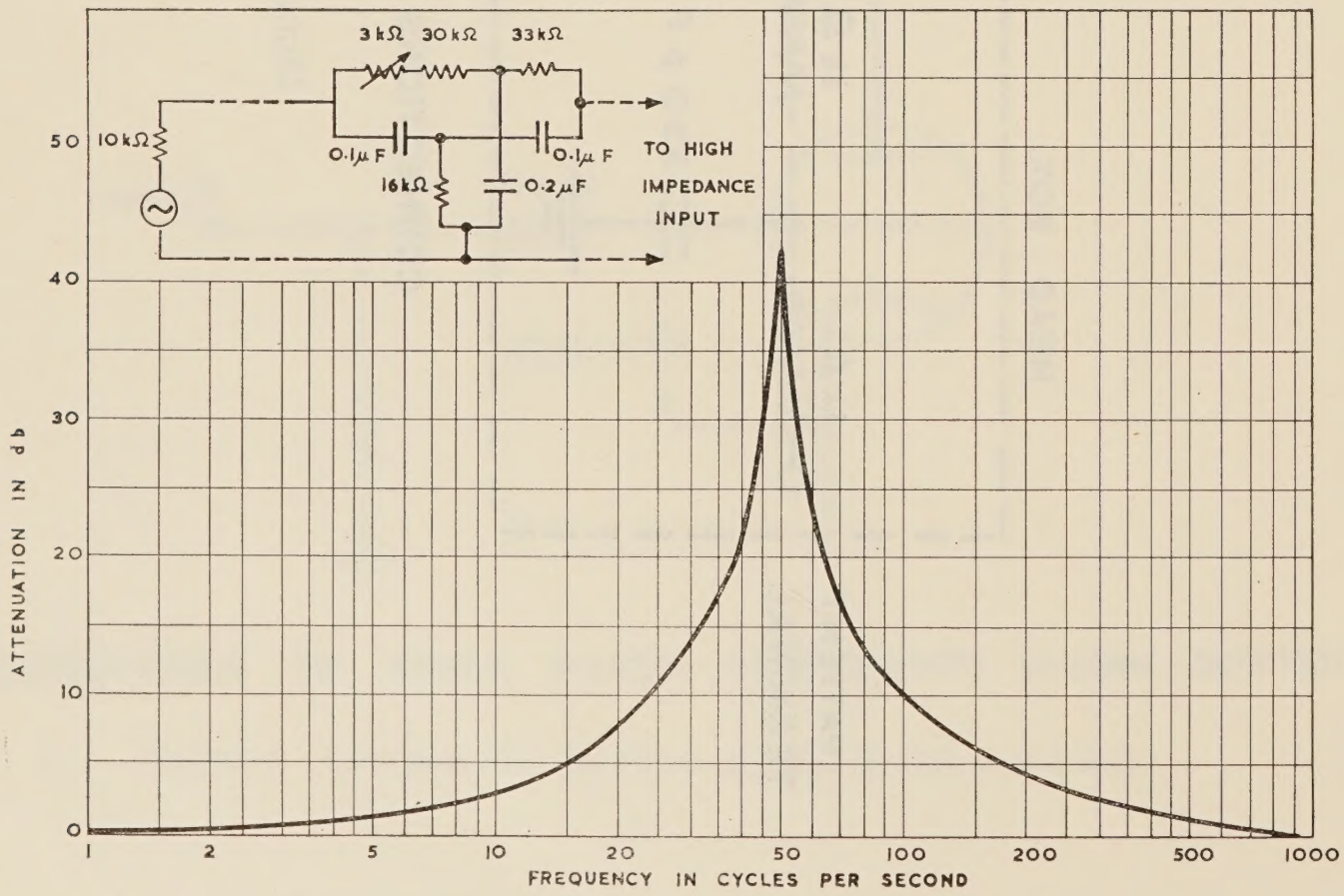


FIGURE 6. Circuit diagram and response curve of a twin "T" low frequency band stop filter

Mains filters for apparatus

36. Extraneous signals on the supply mains can penetrate to recorders or indicators of sensitive mains operated apparatus and appear as "noise" which can cloud wanted signals. Where sensitive circuits are supplied from the secondary winding of a mains transformer incorporated within the apparatus, it has been found that an earthed metallic screen between the primary and secondary windings will assist in filtering high frequency and transient potentials and so reduce the possibility of their interfering with the secondary circuits.

37. Where sensitive circuits are supplied directly from the mains or where a higher degree of suppression is necessary it may be desirable to incorporate filter components in the mains input circuit. The schematic arrangement of a typical mains filter suitable for electro-medical apparatus is shown in Figure 7.

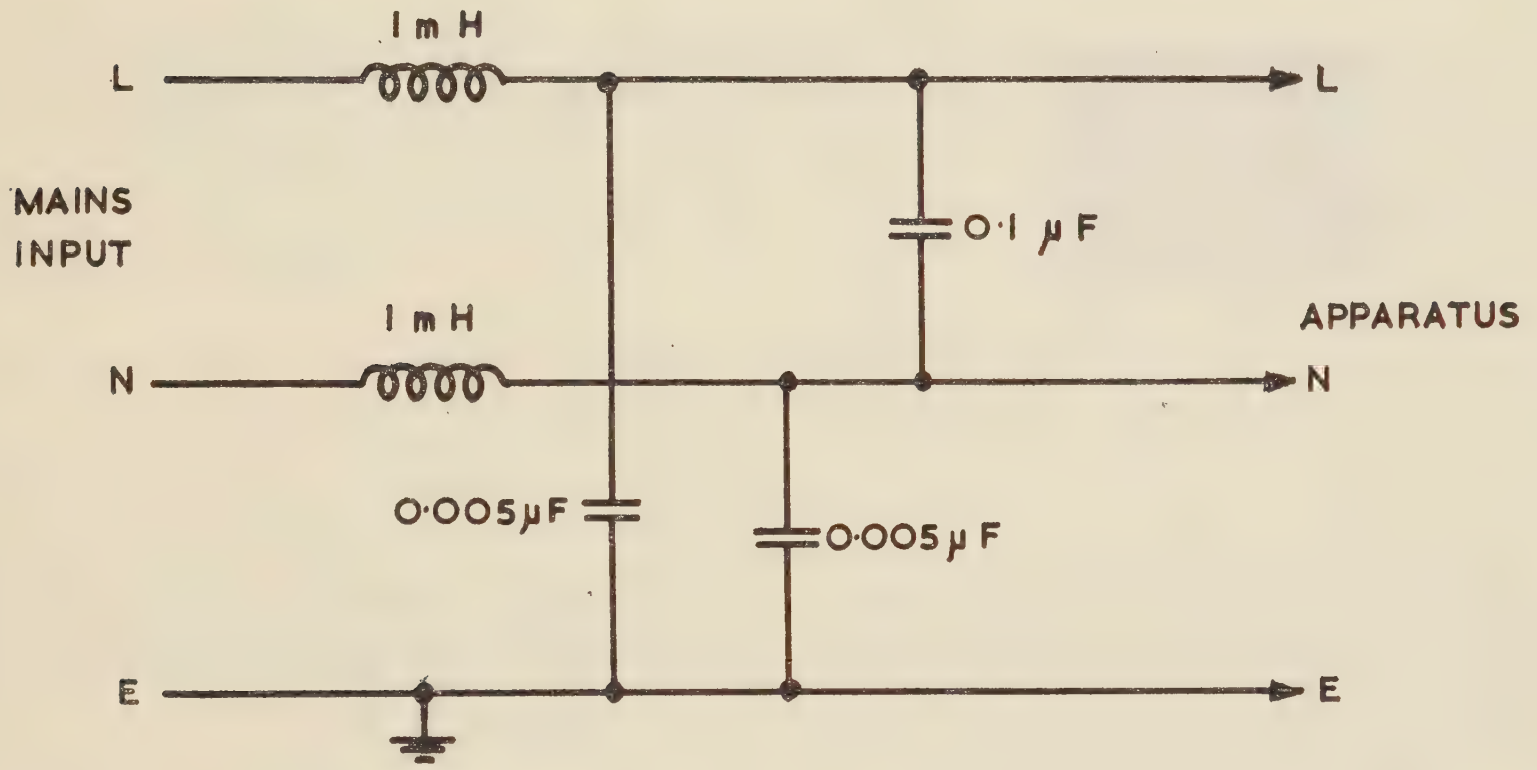


FIGURE 7. Mains filter for apparatus

Selection of new electro-medical apparatus

38. Tests have revealed wide differences in the degree of interference rejection incorporated in apparatus by different manufacturers and the characteristics of apparatus in this respect should be taken into consideration when equipment is purchased. Attention should also be given to the possibility of electro-medical apparatus causing interference. As a minimum requirement equipment which is capable of radiating interfering signals should comply with the limitations specified in the Wireless Telegraphy (Control of Interference from Electro-Medical Apparatus) Regulations 1963. See para. 16.

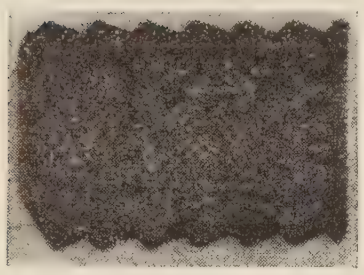
39. Diathermy apparatus which is either exempt or dealt with specially in the Statutory Instruments, is the most frequent source of interference and methods of securing a reduction of interference with diatheramy apparatus are dealt with in the following paragraphs.

Medical diathermy apparatus

40. Medical (short-wave) diathermy units are the most frequent sources which interfere with sensitive electro-medical apparatus in hospitals. The assigned operating frequency (27·12 Mc/s±0·6%) is considerably higher than the frequency range dealt with in physiological measurement and such high frequencies can easily be rejected from the input circuits of physiological measuring apparatus. The difficulties, however, arise from the presence of low frequency (50 or 100 c/s) signals modulated on the radiated high frequency carriers due to the use of a mains frequency power supply for the high frequency generating circuits. The substitution of smoothed direct current for alternating current in these circuits can reduce considerably the degree of interference caused by this type of equipment. The amount of low frequency modulation present is usually expressed as a percentage variation of the high frequency output and in practice it varies from 100% to less than 10%. A diathermy set having 100% modulation depth will cause more than ten times the amount of interference that a set having only 10% modulation depth will cause when operated at the same distance from sensitive equipment. Typical modulation waveforms are shown in Figure 8.

100% modulation 50 c/s (half-wave rectified). Obtained when a 50 c/s supply is applied direct to a single valve oscillator.

100% modulation at 100 c/s (50 c/s full wave rectified). Obtained when a 50 c/s supply is applied to a two valve oscillator via a central tapped transformer.



6% modulation at 100 c/s (50 c/s full wave rectified and smoothed). Obtained where a rectifier valve is incorporated in the anode supply to the oscillator.

FIGURE 8. Typical medical diathermy waveforms

41. The operating frequency of all new medical diathermy apparatus should be within the limits specified in the Statutory Instrument, and the depth of modulation should not exceed 30%.* Where, however, diathermy is liable to be used in an area where freedom from interference is of particular importance a shallower depth of modulation should be specified, e.g. 10% or less. The high frequency and associated components should, as far as is practicable, be enclosed in earthed metal and a screened lead used for the mains connection.

Surgical diathermy

42. The operating frequencies for surgical diathermy are not controlled by any Statutory Instrument, national or international agreement and are, therefore, chosen to suit functional requirements. The frequencies used are usually within the range 0·3 to 3 Mc/s. Some sets operate on two different frequencies, a high one for cutting and a lower one for coagulation. Many present-day machines employ electronic high frequency generation, but spark gap machines are still preferred by some surgeons, particularly for coagulation. To meet these preferences some machines contain both electronic and spark gap high frequency generators. The frequency control with spark gap machines is much looser, the band width wider and harmonic generation is increased but the interference range may be slightly less due to the lower operating frequencies usually used with spark gap machines. Because of the higher operating frequencies of electronic machines, however, interfering signals propagated by them can be more easily rejected (see paras. 26–32).

43. As with medical diathermy the interference is largely due to the use of alternating current in the high frequency circuits causing the radio frequency output to be 100% modulated at mains frequency.

44. Recently, surgical diathermy apparatus has been developed which has a high frequency pulsed output. The frequency of the pulses can be varied for different surgical applications and, except in the lowest frequency position, the pulse modulation frequency will be above the normal physiological frequency range, consequently interference caused by this type of apparatus will be much less than that caused by conventional surgical diathermy apparatus.

45. The need for freedom from electrical interference in operating suites will vary with the types of surgery and the extent that sensitive electro-medical apparatus is used. Physiological monitoring and closed-circuit television in operating suites seems likely to assume greater importance in future and while it may not be possible completely to eliminate electrical interference from surgical diathermy it can be considerably reduced, for example by using electronic diathermy apparatus having a high frequency pulsed output, and by incorporating appropriate filters in the input circuits of the monitoring apparatus together with suitably screened wiring and leads.

*The Ministry's recommended specification for short-wave diathermy issued in April 1959 specified that the depth of modulation should not exceed 30%.

VIII. Interference suppression: installations

46. Various items of installed equipment can be a source of interference either by means of radio-frequency radiation or by causing transients on the mains wiring. The basic requirements for minimising such interference are, (i) enclosure of possible radiating sources and associated wiring in earthed metal and (ii) provision of suppression components in the mains connections to apparatus which is liable to generate radio frequencies or transient potentials. Precautions appropriate to electrical installations and various types of installed equipment are discussed in the following paragraphs.

Mains-borne interference

47. Where a medium voltage supply is shared by other users, some of the noise voltages present on the mains may be generated outside the hospital. Where a hospital is supplied from a separate sub-station the mains-borne interference will be almost entirely that generated within the hospital.

Segregation of circuits

48. The circuits supplying physical medicine and radiological departments, operating suites, premature baby wards, laboratories, workshops, and kitchens and lifts are most likely to pick up and transmit interference signals and, as far as is reasonably practicable, circuits which will supply sensitive apparatus should be routed clear of these circuits.

Enclosure of mains wiring and accessories

49. All installed wiring at mains potential should consist of mineral insulated, metal clad cables or be enclosed in heavy-gauge screw-jointed conduit or steel trunking. Plastic conduits and unenclosed heating cables should not be used in areas where freedom from electrical interference is necessary.

50. Switches, socket outlets, fuseboards and other installation components should be housed in earthed metal enclosures.

Flexible wiring

51. Flexible supply cords to mains operated equipment in interference-free areas should incorporate a metallic screen throughout their length, which should be additional to the usual earthing continuity conductor and should be electrically bonded at each end to any exposed metal at the terminations. The metallic screen should be sheathed externally with a suitable insulating material.

52. The neutral conductor of each electrical distribution system should be " earthed " at the sub-station only. Local earthing of the neutral can result in stray earth currents flowing in conduits and other exposed metalwork and cause magnetic fields which can interfere with sensitive apparatus. For this reason earthed wiring systems should not be used in hospitals.

Mains suppressors

53. Suppression components can be used to prevent unwanted signals being injected into the mains: they can also be used to filter the mains input circuits of sensitive apparatus.

54. Suppression components should be located close to the generating source or, when used as a filter, should be located close to the supply terminals of the apparatus to be protected, preferably within the apparatus. In screened rooms, however, the filter unit should be located outside the screening but close to the point where the circuits enter the screen (see para. 91).

55. The simplest suppressor or filter will consist of a single capacitor connected between the line conductor and earth or between the line and neutral conductors. Such an arrangement will be satisfactory in many instances and particularly with highly inductive circuits. With circuits having comparatively low inductance or where the highest degree of suppression is required, it will be necessary to use a combination of chokes and capacitors, so that the choke offers a high impedance to the passage of interference signals and the capacitors provide a low impedance between conductors and/or to earth. As the chokes will be in series with current-carrying conductors they must have a current rating at least equal to the maximum loading of the circuit. The schematic arrangement of a typical mains filter unit is shown in Figure 9.

Particle accelerators

56. Linear and spiral accelerators, cyclotrons, betatrons, etc., usually incorporate a high voltage, high energy pulse generator which is the main interference propagating source associated with this type of apparatus. A strong magnetic field used with the apparatus is also a possible source of interference.

57. Where the pulse generator is located in the treatment room, there should be no interference problems, as the screening against radiation effects, e.g. mass concrete, will normally also effectively attenuate interference signals. The pulse generator, however, is frequently installed outside the radiation screening to enable testing to be carried out free from radiation hazards. In these instances it may be necessary to take other appropriate measures to minimise the effects of the radiated interference, e.g. physical separation (see Section IX).

Staff location systems

58. Electronic staff location systems fall into three categories as follows:

(i) Inductive loop systems operating at low frequencies, e.g. 400-13,000 c/s.

(ii) Inductive loop systems operating at higher frequencies and employing a modulated carrier.

(iii) Direct radio transmissions on 31·75 Mc/s.

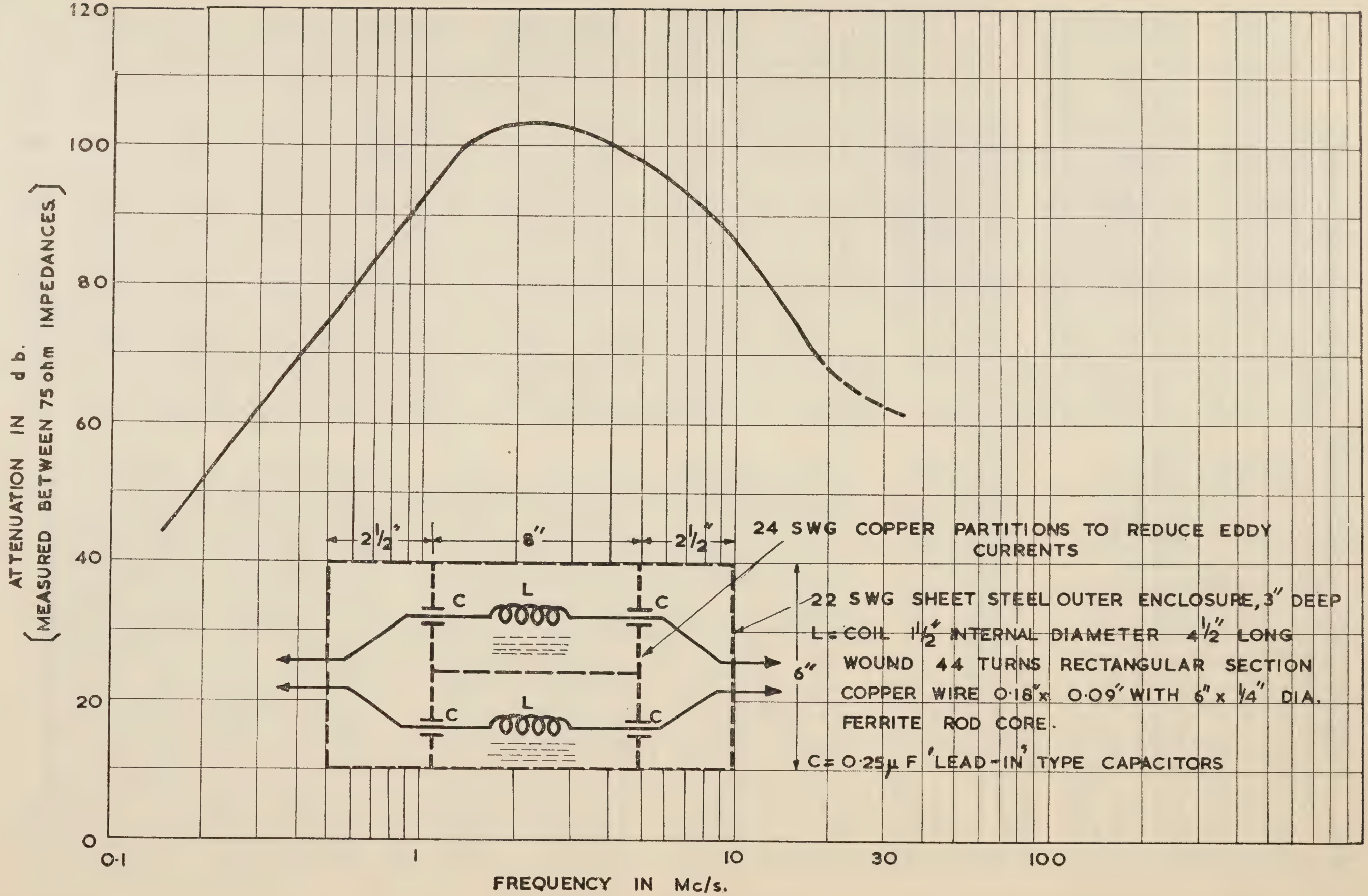


FIGURE 9. 30 amp. mains filter

59. Interference is much more likely from low frequency inductive loop systems, particularly with E.M.G.s and similar apparatus working at frequencies which are within the frequency range of the loop system. Low frequency systems are also liable to cause interference to telephone and other wired sound systems.

60. If serious interference should be experienced with existing low frequency inductive loop systems it will usually be necessary to raise the operating frequency to a value above the biological range. This will usually mean the provision of new central equipment and personal receivers.

61. New inductive loop systems should be of the modulated carrier type and operate at frequencies above 18 kc/s. Under these conditions interference is less likely to occur but may still arise if strong magnetic fields are used.

62. The aim with new installations, therefore, should be to use sensitive receivers and to keep field strengths down to the minimum that will ensure satisfactory results.

Lifts

63. The two main sources of interference associated with lift installations are the spark producing components in the lift motor room, e.g. contactors, rotary converters and motors, and the control contacts in the lift cars and at each floor level. In practice, sparking sources in the lift cars are more likely to cause trouble as the travelling cables are unscreened.

64. As far as is practicable, all sparking contacts and wiring should be totally enclosed in earthed metal.

65. In most instances it will be possible to prevent interference from lifts by separation (see Section IX). Where there is the possibility of interference from the controls, via the travelling cables, interference suppressors should be fitted as close as possible to the sources.

Power transformers

66. Transformers connected to mains electricity will produce a 50 c/s magnetic field, the extent of which will depend on the power rating and the magnetic shielding of the transformer. This field may cause potentials to be induced in any electrical conductors in the area.

67. Adequate separation is the best means of safeguarding against this type of interference and as the induced voltage is in inverse proportion to the cube of the distance, only comparatively short distances are usually necessary to avoid this type of interference (see Section IX).

Switches, relays, thermostats, etc.

68. Various means of interrupting and controlling circuits can cause interference either by sparking, which will result in the generation of radio frequency signals which may be conducted along or radiated from the associated wiring, or by producing surges on the mains due to the large rate of change in current. The intensity of the interference will depend on a number of factors including the energy dissipated in the spark, speed of operation of the contacts, circuit inductance and whether the wiring is screened.

69. Complete enclosure of sparking sources and associated wiring in earthed metal will reduce the radiation. Where further protection is required suppression components should be fitted as close as possible to the contacts (see paras. 53–54).

70. Solid state (semi-conductor) switching is being used increasingly instead of conventional switching methods and one of its advantages is the elimination of sparking, although it should be noted that interfering potentials on the mains may still occur with rapid switching. Solid state switching is likely to be more expensive than conventional types of control but the higher cost may be justified in areas where freedom from interference is important.

Electric clocks

71. Both synchronous and impulse type clocks can cause interference over a limited area (see Table 1 after para. 84). The interference can be minimised by providing an effective earthing connection to all non-current carrying metal parts but the most effective safeguard is to ensure that electric clocks are not installed in areas where freedom from electrical interference is required.

Lighting fittings

72. Fluorescent lamps produce an electrostatic field at mains frequency and are occasionally liable to generate a high frequency signal, thus they can cause interference to nearby sensitive apparatus. This can be reduced by fitting an earthed metal mesh over the tubes; a mesh size similar to that recommended for screened rooms (Figure 12) is suitable. A typical screen is shown in Figure 10. The chokes of fluorescent fittings can cause a limited magnetic field.

73. The electrostatic field from filament lamps is smaller but can be troublesome if the lamps are too close to sensitive apparatus. Again interference can be minimised by enclosing the lamp in an earthed metallic mesh but it will usually be possible to avoid interference from filament lamps by adequate spacing (see Table after para. 84).

Electric motors

74. Appliances such as vacuum cleaners, floor polishers, ventilation fans and various kitchen machines employ electric motors which are liable to spark in use and be a source of electrical interference. The suppression of interference from electric motors

such as may be used in these appliances is covered by Statutory Instrument No. 291, The Wireless Telegraphy (Control of Interference from Electric Motors) Regulations 1955. This Statutory Instrument is applicable to motors, generators and converters having a continuous rating less than 1 horsepower or 0·75 kilowatt per 1,000 revolutions per minute.

75. Compliance with this Statutory Instrument is not mandatory upon the manufacturers and should, therefore, be specified when motors or generators or equipment incorporating motors or generators which come within its scope, are purchased. Motors and generators which are outside the scope of the Statutory Instrument and any existing motors and generators which are liable to be a source of interference should be suppressed to comply with the recommendations of B.S.800. Figure 11 shows a typical suppression arrangement for electric motors.

Refrigerators

76. Interference suppression from refrigerators is covered by Statutory Instrument No. 292, The Wireless Telegraphy (Control of Interference from Refrigerators) Regulations 1955. The requirements of this are similar to those of Statutory Instrument No. 291 except that limits are specified only for the noise voltages on the mains. Since refrigerator motors are invariably totally enclosed in earthed metal, trouble from high frequency radiation is unlikely.

77. Compliance with Statutory Instrument No. 292 is mandatory upon manufacturers, therefore all new refrigerators should comply with its provisions. Any existing refrigerators not complying should be suitably suppressed (see Figure 11).

Suppression capacitors

78. Special attention is necessary in specifying the voltage and capacitance ratings of suppression capacitors, particularly where they will be used where leakage through the capacitor or a failure of the capacitor insulation or earth connection can introduce the risk of electric shock.

79. The basic safety requirements are:

(i) Capacitors which are connected between the supply mains and exposed metal parts should have a maximum nominal capacitance of 0·005μF.*

(ii) The maximum nominal capacitance between live and neutral conductors should not exceed 0·1μF.†

(iii) Capacitors which are connected between the supply mains and exposed metal parts or in any situation where failure would lead to the danger of electric shock, should be capable of withstanding a test voltage (d.c.) equal to nine times the rated voltage. Other suppression capacitors should be capable of withstanding a test voltage of 4·5 times the rated voltage.

(iv) Capacitors should not be connected to exposed metal parts on all-insulated or double-insulated appliances.

(v) Capacitors should preferably be so connected that they are disconnected from the supply when the equipment they are associated with is not in use.

(vi) Capacitors which are capable of retaining a dangerous charge should be fitted with " bleed resistor(s) " which will ensure that they are discharged to less than 30 volts within 1 sec. of switching off the supply.

(vii) Capacitors should comply with B.S.613 as applicable.

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* Capacitors which are connected between the live conductor and exposed metal parts can give rise to stray earth currents which can cause troublesome magnetic fields. They can also cause an electric shock hazard under certain conditions. In most instances capacitors between live and neutral conductors, supplemented with chokes where necessary, will provide a satisfactory filter.

Where it is necessary to connect capacitors between the supply mains and exposed metal parts the smallest value capacitor practicable should be used.

†This value may be increased up to 2·0 μF where the capacitor is connected on the appliance side of a mains switch on the appliance.

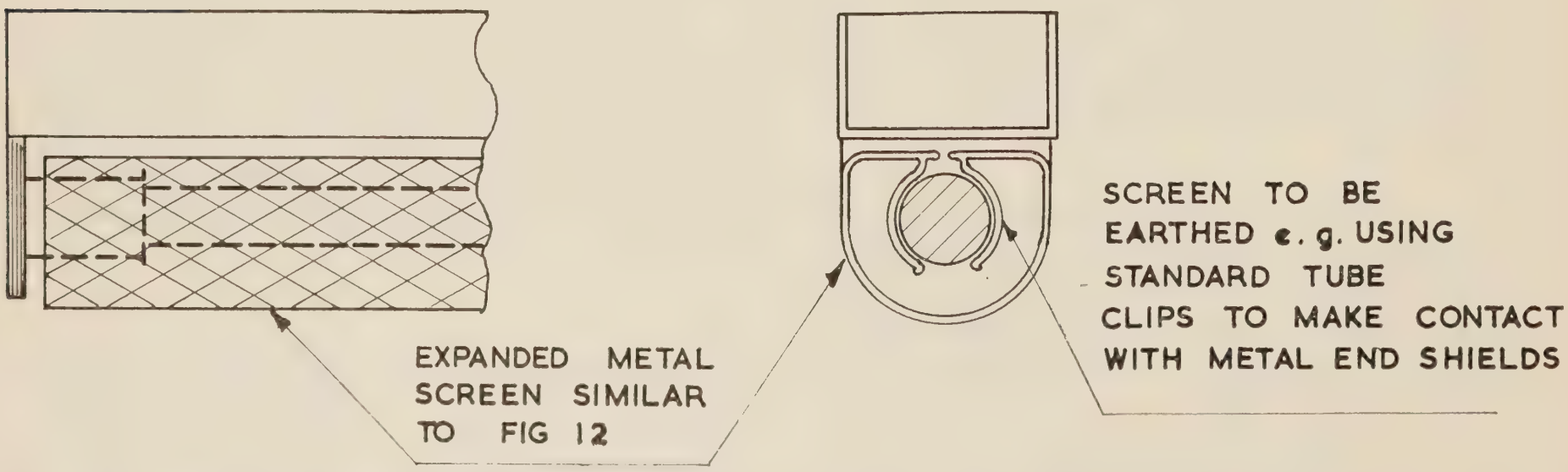

FIGURE 10. Screen for fluorescent lighting fitting

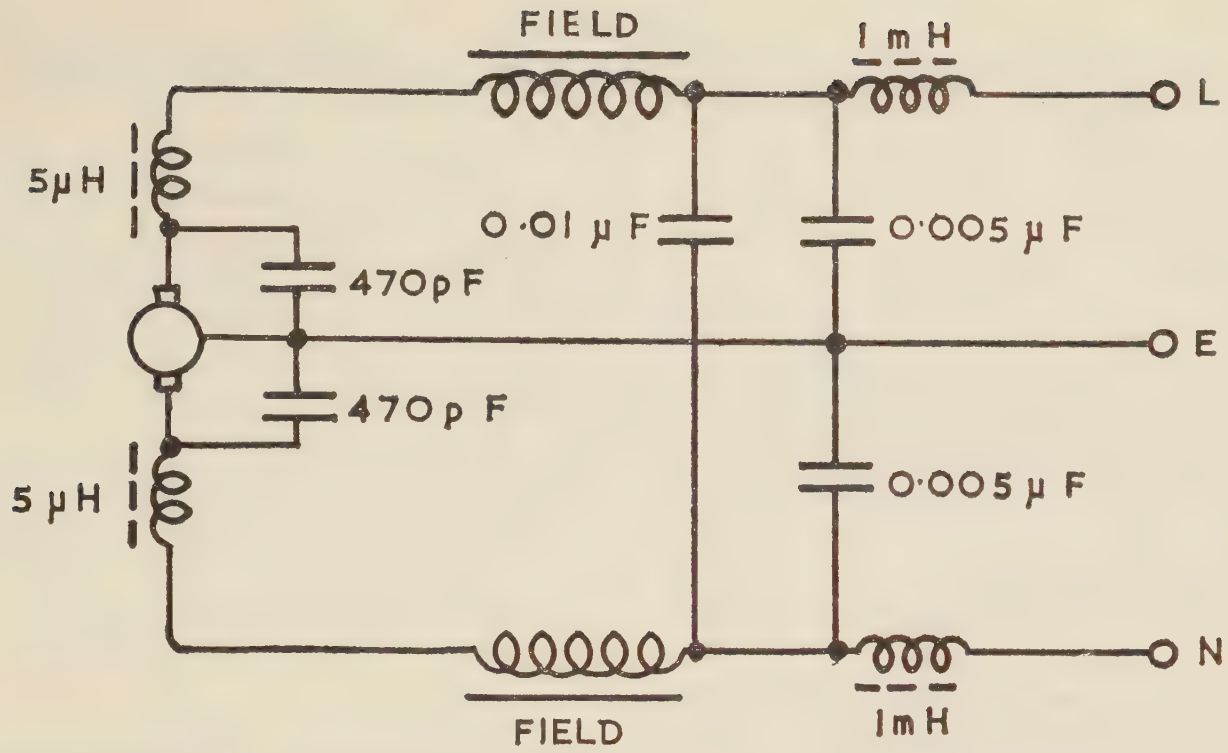

FIGURE 11. Typical medium and high frequency suppression for commutator type motor

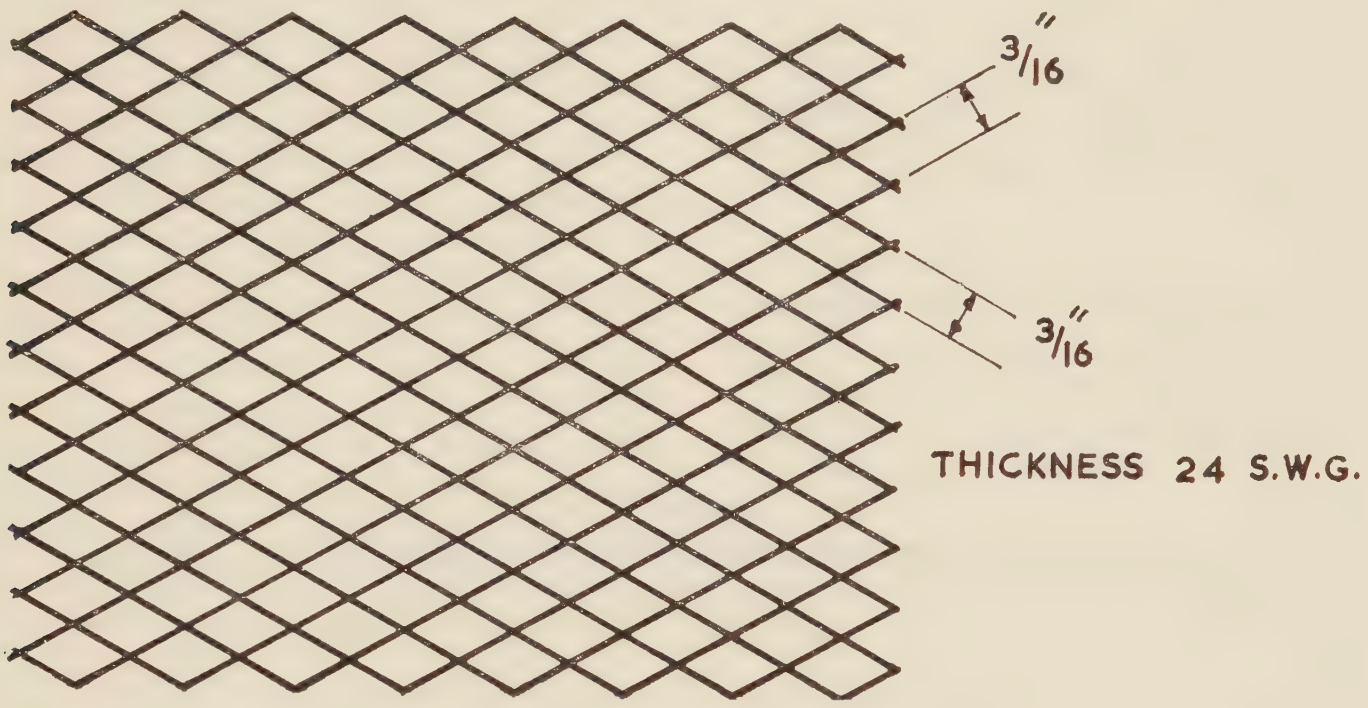

FIGURE 12. Expanded steel or aluminium suitable for screening (actual size)

IX. Physical separation of interfering sources and sensitive apparatus

80. Where possible, especially when planning new hospitals, the aim should be to allow adequate physical separation between possible interfering sources and areas where sensitive apparatus may be used. The minimum separation to ensure freedom from interference will depend on several factors and will, therefore, vary with different types of equipment. For the frequencies and distances under consideration the effect of radiated signals from local sources can be assumed to vary inversely as the square of the distance.

81. The distances given in Table 1 below are intended as a general guide only, to assist in assessing the possibility of interference being experienced. In arriving at these distances a typical interference source and no special suppression is assumed. In practice it will usually be possible to reduce the distances considerably by the use of apparatus filters (see para. 26) and/or by the use of suppressors at the source (where applicable).

82. The distances given in Table 2 below are intended to be a guide to the minimum physical spacing which will be necessary under average conditions in hospitals where appropriate measures (other than room screening) have been taken as recommended elsewhere in this document, to reject or suppress interference signals within the sensitive apparatus referred to.

83. In arriving at the larger distances in the tables an allowance has been made for the screening effects of ordinary walls and partitions such as are likely to be met in normal hospital layouts.

84. Where the distances specified in Table 2 cannot be obtained, it can be assumed that special room or other screening (see Section X) will be necessary.

TABLE 1

Approximate minimum spacing for interference-free working with unfiltered apparatus

Source of interference	*Distance in feet*		
	E.M.G. etc. sensitivity 20 μv/cm	*E.E.G. etc. sensitivity 100 μv/cm*	*E.C.G. etc. sensitivity 1000 μv/cm*
Medical diathermy* (27 Mc/s 100% modulation) ...	200	200	100
Medical diathermy (27 Mc/s 30% modulation)	100	100	60
Medical diathermy (27 Mc/s 10% modulation)	60	60	30
Surgical diathermy (valve type)	70	50	30
Surgical diathermy (spark gap type)	50	30	20
Surgical diathermy (H.F. impulse type)	30	15	10
Linear accelerator† (impulse generator)	100	70	50
L.F. inductive loop (paging) distance outside loop‡ ...	20	0	0
Lift motor rooms (controls unsuppressed)	30	20	10
Lift wells (controls unsuppressed)	30	20	10
Power transformers (100–750 kVA)	30	30	30
Small transformers up to 1 kVA	5	5	5
Commutator motors (unsuppressed)	20	15	10
Thermostats, relays and other switching devices (unsuppressed)	20	15	10
Electric clocks (mains and impulse types)	10	5	5
Fluorescent lamps	15	10	10
Tungsten lamps	10	5	5

TABLE 2

Approximate minimum spacing for interference-free working with filtered apparatus

Source of interference	*Distance in feet*		
	E.M.G. etc. sensitivity 20 μv/cm	*E.E.G. etc. sensitivity 100 μv/cm*	*E.C.G. etc. sensitivity 1000 μv/cm*
Medical diathermy* (27 Mc/s 100% modulation) ...	60	40	40
Medical diathermy (27 Mc/s 30% modulation)	50	30	30
Medical diathermy (27 Mc/s 10% modulation)	30	20	20
Surgical diathermy (valve type)	20	10	10
Surgical diathermy (spark gap type)	20	10	10
Surgical diathermy (H.F. impulse type)	15	10	10
Linear accelerator† (impulse generator)	50	30	30
L.F. inductive loop (paging) distance outside loop‡ ...	20	0	0
Lift motor rooms (controls unsuppressed)	10	10	10
Lift wells (controls unsuppressed)	10	5	5
Power transformers (100–750 kVA)	30	30	30
Small transformers up to 1 kVA	5	5	5
Commutator motors (unsuppressed)	20	5	5
Thermostats, relays and other switching devices (unsuppressed)	20	5	5
Electric clocks (mains and impulse types)	10	5	5
Fluorescent lamps	15	10	10
Tungsten lamps	10	5	5

*For interference-free working with old medical diathermy sets operating on 40–50 Mc/s it will be necessary to increase the distances given.

†Applicable only where the generator is installed outside the radiation screening. When installed within the radiation screening no interference should be experienced.

‡There is a possibility of interference being experienced within a L.F. inductive loop with E.C.G. and E.E.G. apparatus. Interference within this type of loop is much more likely with E.M.G. apparatus.

X. Screened rooms

General

85. As is clearly stated in earlier paragraphs, most interference problems can be dealt with satisfactorily without resorting to the use of screened rooms, and this form of protection will only be necessary where very sensitive apparatus, e.g. E.M.G., will be used in close proximity to equipment which is likely to generate interference signals. With less sensitive apparatus such as E.C.G. and E.E.G. satisfactory working should be possible in most instances where appropriate steps have been taken to minimise or suppress interference. The distances in Table 2 are intended as a guide to be used in deciding whether or not room screening will be necessary.

86. Where room screening is necessary it must be complete to be effective against radio frequency signals. Tests have shown that partial screening, e.g. excluding doors and windows, is not effective against this type of interference, but will assist in reducing electrostatic and magnetic interference, the latter of course being dependent on the use of a ferrous screening material. Partial screening against electrostatic interference from adjacent rooms, etc., can be obtained by painting walls with an electrically conducting paint, e.g. a graphite loaded epoxy resin paint having a film resistance not exceeding 500 ohms per square. This treatment is particularly desirable where E.M.G., E.E.G. and E.C.G. rooms are formed with lightly constructed partitions, i.e. construction other than brick or slab. Normal wall finishes can be applied over the conducting coat when dry.

Examples where room full screening may be required are:

Electro-myography rooms

87. Where located near high-frequency generating apparatus, e.g. in a physical medicine department where diathermy apparatus will be used and the physical separation specified in Table 2 cannot be obtained.

Operating suites

88. Room screening of operating theatres may be necessary where two or more theatres adjoin or are closely located and sensitive physiological monitoring apparatus is likely to be used in the theatres. Where a separate apparatus room is provided in the suite this also may require screening. It should be noted that room screening will not be effective against interference radiations within the room but will reduce interference, e.g. where diathermy is used in an adjoining theatre. Since diathermy is the primary source of interference in operating suites the use of diathermy apparatus which is less liable to cause interference, e.g. high frequency type (see paragraph 44), is desirable where freedom from interference is important and in these circumstances room screening may not be necessary.

Basic requirements for room screening

89. To screen a room against external sources of interference the walls, floor, ceiling, windows and doors forming the room must incorporate or be faced with an electrically conducting membrane which is electrically continuous throughout. Ideally screening should be electrically insulated from all external conductors except for an effective low impedance earthing connection at one point only. In practice it will usually be necessary to run engineering services into the room and it will, therefore, be necessary to take appropriate steps to prevent these bringing in unwanted signals.

90. Where practicable all service pipes and conduits should enter the room at the earthing point and should be electrically bonded to the earthing conductor. It should be arranged that service pipes do not pass through the room. Where this cannot conveniently be arranged, pipes should be bonded to the screening at the entry and exit points and an electrically insulating section incorporated immediately outside the entry and exit points.

91. Electrical circuits entering the screening should incorporate filters which should be located outside the room but as close as is practicable to the entry point. All conductors, including flexible cords and electrical components within the room, should be screened with earthed metal (see paras. 49–51).

92. Sources of possible interference within the room should be suitably suppressed at source (see paras. 53–55).

Size of enclosures

93. With large screened rooms there is increased risk of cavity resonance, and to minimise this possibility enclosures having any dimension exceeding 20 ft. are not recommended.

Materials

94. For radio frequency and electrostatic screening any material that is a good electrical conductor is suitable. For magnetic screening, e.g. against low frequency (mains) interference signals, a ferrous material is superior.

95. In general the higher the conductivity of the screening material the greater the attenuation. In practice, however, the many joints which will be necessary in forming the conducting membrane may be the limiting factor and the resistivity of the joints tends to be more important than that of the screening materials itself. The aim should, therefore, be to ensure good electrical conductivity at joints and to eliminate unnecessary jointing.

96. Materials should be chosen to prevent the possibility of significant electro-chemical potentials at joints between dissimilar metals and thereby intro-

duce the risk of electrolytic action, particularly in situations where dampness may be expected. Metals differing by more than about 0·5 volt in the electrochemical series should not be used in direct contact with each other, but may be connected via a third metal provided this potential difference is not exceeded. For example, copper and steel (or zinc) should be connected via a brass or gunmetal washer or lug. It is desirable to avoid joints between dissimilar metals where they are buried in plaster or other moisture absorbing materials.

97. Materials used should have resistance to corrosion, e.g. steel, should have a galvanised finish. The use of aluminium in walls containing lime or cement is not recommended.

98. Expanded steel having an electro-galvanised finish has been found to be effective and an economical material to use in buried situations. Details of a suitable mesh are given in Figure 12. In operating theatres, there is no objection to this mesh being used in anti-static floors instead of that recommended in Hospital Technical Memorandum No. 2. For screening purposes, however, the floor mesh should be electrically continuous with that incorporated in the walls, etc.

99. For surface applications a metallic sprayed coating, copper or aluminium foil or galvanised steel faced plywood, can be used. Expanded aluminium is also suitable for non-buried situations, e.g. for screening windows. Additional information on available sizes and costs of materials are given in Appendix II.

100. Door and window frames should preferably be constructed of steel and have a hot dipped galvanised coating complying with B.S.729 Part 1.

Joints

101. Joints in the conducting membrane should be reduced to a minimum by the use of the largest width of material obtainable and by avoiding unnecessary joints in the lengths.

102. Joints should butt closely or overlap and be electrically bonded at intervals not exceeding 18 ins. along the joint. The membrane material should be bonded at similar intervals to steel door and window frames. It is preferable that joints in ferrous materials, e.g. expanded steel, are welded. Joints in non-ferrous metals should be soldered.

Doors

103. Doors should be completely screened and there should be good electrical continuity between the door and the door frame and between the door frame and the remainder of the room screening.

104. An expanded metal membrane similar to that recommended for walls can be incorporated within the door and bonded to a metal edging around the door. Alternatively copper or aluminium foil not less than 0·001 in. thick can be used.

105. It will be necessary to provide some means of ensuring good electrical contact between the door and the door frame. This can be achieved by attaching a phosphor-bronze strip to three sides of the door frame so that it makes good contact with the metal edging of the door in the closed position (see Figure 13). Where the highest degree of interference suppression is required it will be necessary to arrange contacts along the bottom of the door also. Where this is considered necessary the contact strip should be fitted along the lower edge of the door and arranged to make contact with a metal plate along the threshold (see Figure 14).

106. In operating suites and other areas where aseptic conditions are important the bonding strips can be permanently attached to metal strips which are secured at intervals not exceeding 18 in. so that they can be removed for cleaning purposes.

Waveguide entrances

107. When a screened door is open, the room screening will be incomplete and interference may be experienced. This condition will be acceptable in most instances and where necessary the door can be fastened closed whilst sensitive apparatus is in use.

108. Where conditions will be such that it will be necessary to open a screened door frequently whilst sensitive apparatus is in use, a waveguide entrance can be formed to screen the doorway opening, e.g. by screening the walls, ceiling and floor of the approach corridor.

109. Waveguide entrances are effective only for a range of frequencies dependent on the dimensions of the openings, and the length of the waveguide. The width and height of the entrance, therefore, should be kept as small as is practicable. In hospitals, interference frequencies in excess of 31·75 Mc/s (staff location) are unlikely and to secure satisfactory results up to this frequency limit the height and width should not exceed 10 ft., and a length of 12 ft. is recommended. The arrangement of a typical waveguide entrance is shown in Figure 15.

Windows

110. These introduce problems in ensuring satisfactory continuity of the screening and are best avoided. A close mesh wired glass, e.g. $\frac{1}{4}$ in. mesh, has been successfully used in conjunction with metal window frames having a galvanised finish. Figure 16 shows a typical arrangement. It will be noted that at each edge the glass is cut back so that the wire extends approximately $\frac{1}{2}$ in. The wires are then bent round to make contact with the inside surface of the metal frame.

111. An alternative arrangement is to fit close mesh metallic screens (e.g. as shown in Figure 12), which can be readily removed for window cleaning, to the inside of the windows. The screens must be so arranged that they make good electrical contact with the general room screening at intervals not exceeding 18 in. Figure 17 shows a typical arrangement.

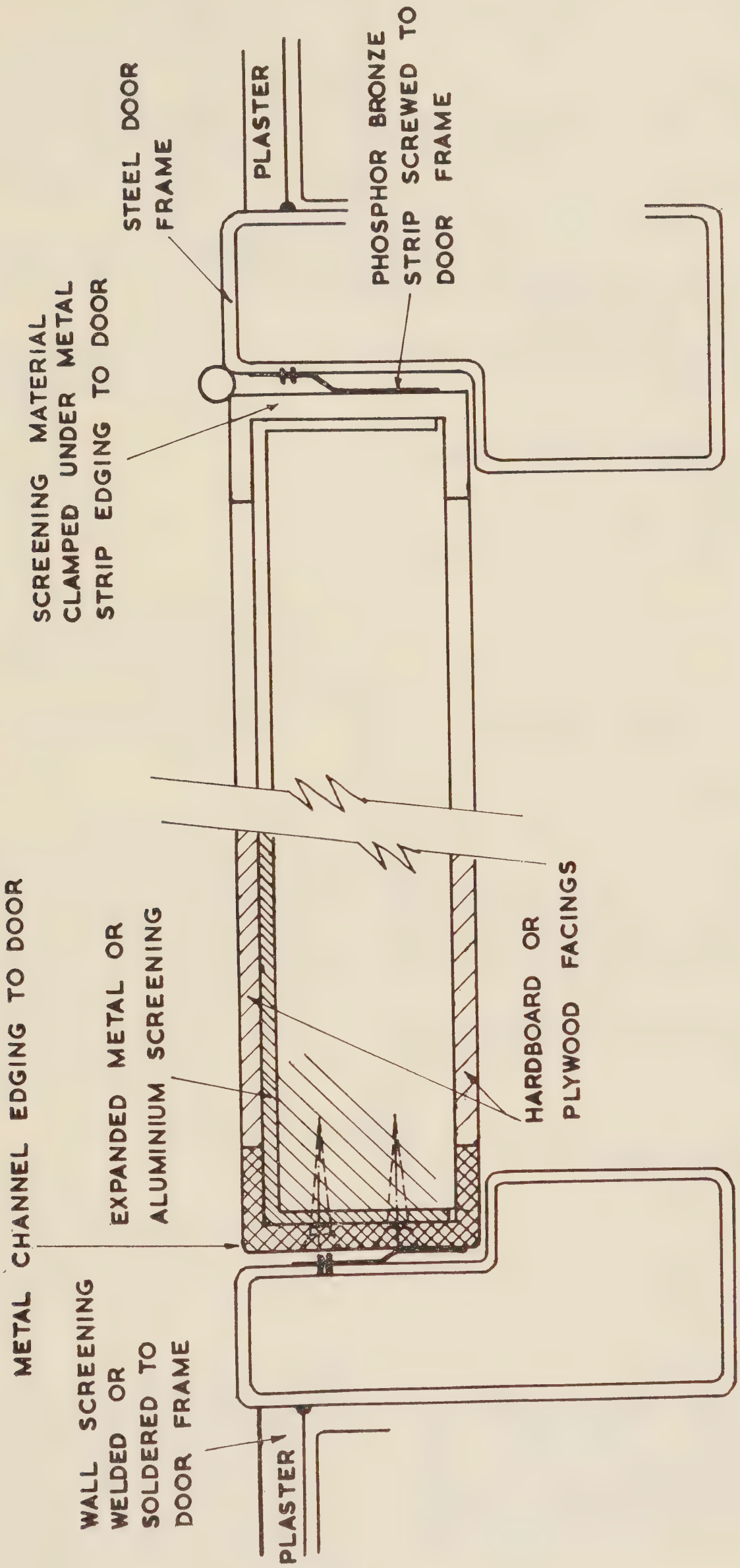
SCREENING MATERIAL CLAMPED UNDER METAL STRIP EDGING TO DOOR
STEEL DOOR FRAME
PLASTER
PHOSPHOR BRONZE STRIP SCREWED TO DOOR FRAME
METAL CHANNEL EDGING TO DOOR
EXPANDED METAL OR ALUMINIUM SCREENING
HARDBOARD OR PLYWOOD FACINGS
WALL SCREENING WELDED OR SOLDERED TO DOOR FRAME
PLASTER

FIGURE 13. Screening of doorway

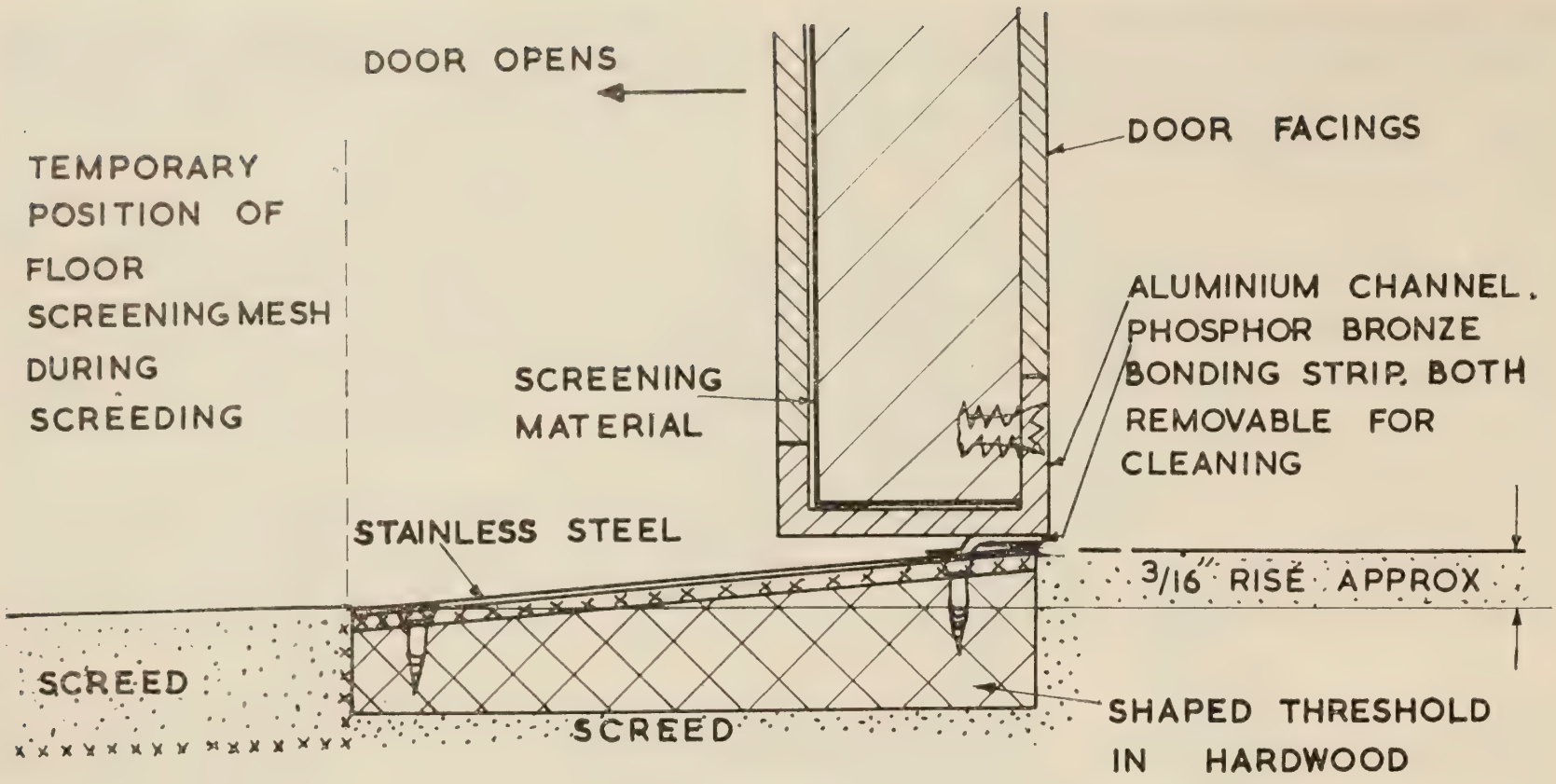

FIGURE 14. Bonding at bottom of door

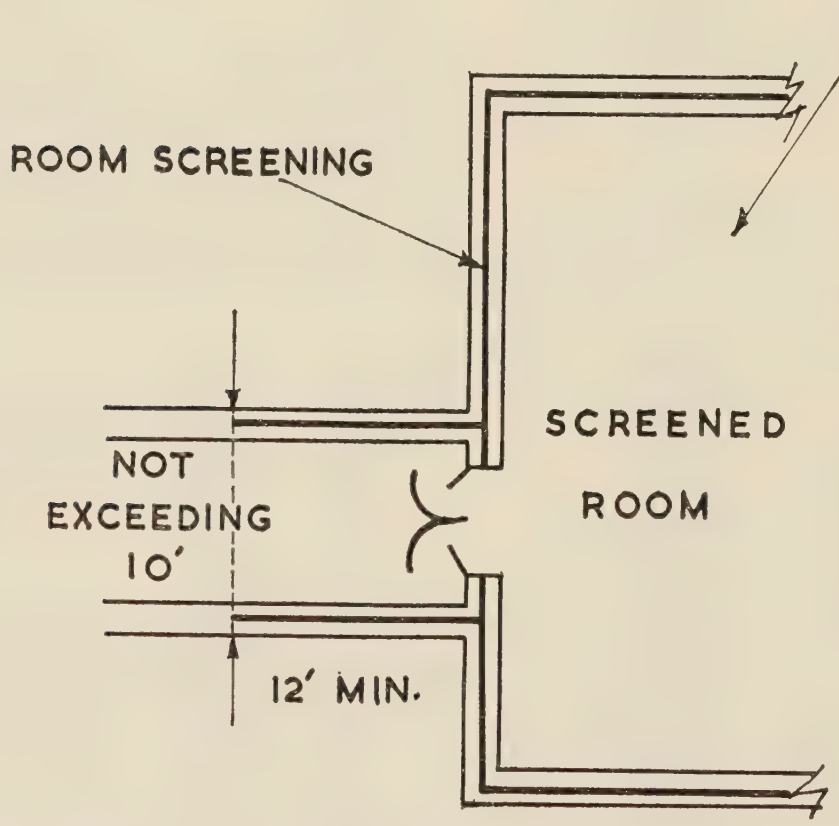

FIGURE 15. Waveguide entrance

Method of construction

112. The screening membrane can be buried in the walls, ceiling and floor or can be applied to the surface after construction. Alternatively a metal faced plywood and steel frame type of construction can be used. The method of construction will have an important influence on choice of material for the membrane.

Buried construction

113. Expanded steel having a galvanised finish has been found to be a durable and economical material for buried situations. Joints between sheets should be close butted or overlap and welded at intervals not exceeding 18 in. Joints between the expanded steel and door and window frames should be welded at similar intervals.

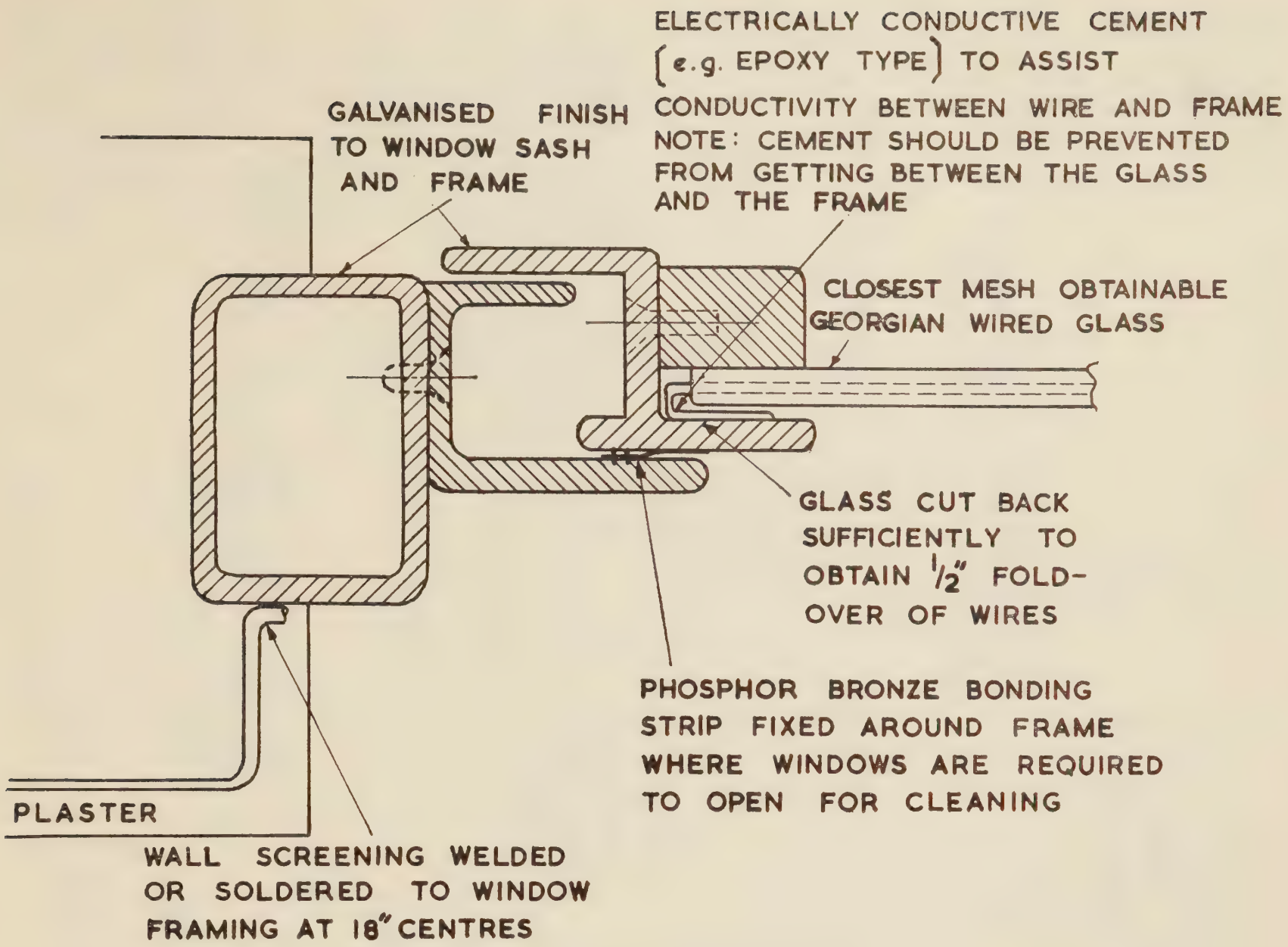

FIGURE 16. Screened window using wired glass

Surface treatments

114. The alternative to a buried form of construction is to apply the membrane to the walls, etc., after construction but prior to any decorative finish. The alternative treatments available are a metallic sprayed finish or a metal foil lining. Details of material and approximate costs of the two methods are given in Appendix II. The spraying technique will usually give the best finish since it is difficult to avoid kinking when applying foils to walls, etc. With either method it is recommended that corners are rounded.

Metallic spray

115. Usually the treatment is applied in two coats, the first being a bonding coat of zinc followed by a copper coating. The sprayed coating will make good electrical contact with steel door and window frames particularly where these have a galvanised finish.

116. The finished thickness of the sprayed coating is usually about 0·002 in. and when sprayed on to flat surfaces a flat matt finish is obtained which can be treated with normal decorative finishes such as gloss or emulsion paints.

117. The sprayed coating on floors should be protected with one of the usual forms of floor covering, but highly electrostatic materials, e.g. vinyl, should be avoided (see para. 9).

Metal foil

118. Copper or aluminium foil can be applied to the surface of walls, ceilings or floors using a suitable adhesive, e.g. an epoxy resin type.

119. Joints between copper sheets and between the sheets and metal door or window frames can be soft soldered.

120. Joints of aluminium foil should overlap and be secured by a suitable electrically conductive adhesive, e.g. an epoxy resin-graphite type.

121. Alternatively, two layers of paper-backed foil 0·0005 in. thick can be used with the metallic surfaces face to face to ensure good electrical contact between the layers. The paper backing of the first layer should be secured with suitable adhesive, e.g. an epoxy resin type. The second layer should be applied with a suitable electrically conducting type adhesive, e.g. an epoxy resin-graphite type, so that the paper surface is exposed. Strips of thicker unbacked foil, e.g. 0·001 in. thick secured with a conducting type adhesive, should be used to obtain good electrical continuity between the paper-backed foil and metal door and window frames.

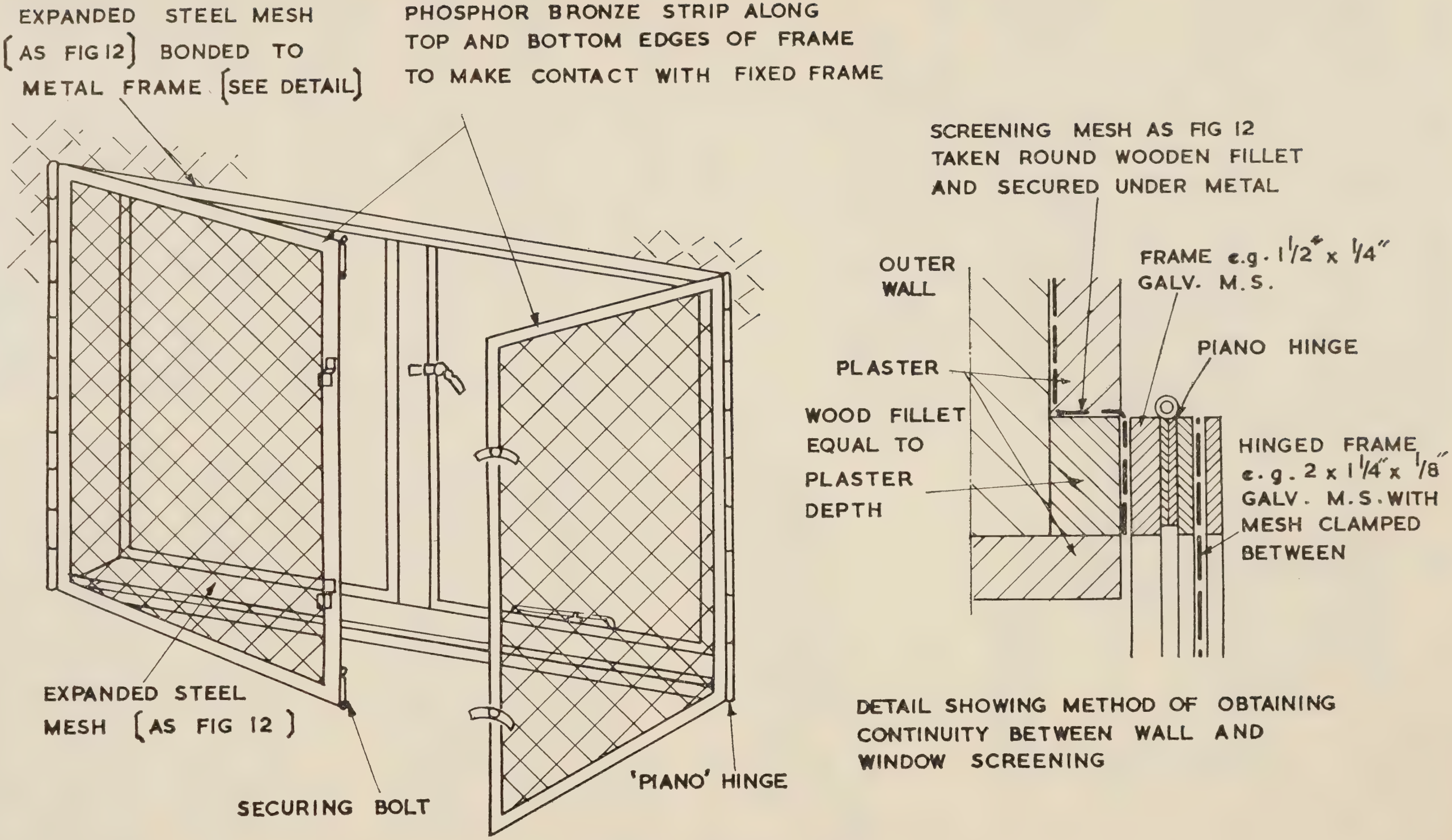
EXPANDED STEEL MESH (AS FIG 12) BONDED TO METAL FRAME (SEE DETAIL)
PHOSPHOR BRONZE STRIP ALONG TOP AND BOTTOM EDGES OF FRAME TO MAKE CONTACT WITH FIXED FRAME
EXPANDED STEEL MESH (AS FIG 12)
SECURING BOLT
'PIANO' HINGE
SCREENING MESH AS FIG 12 TAKEN ROUND WOODEN FILLET AND SECURED UNDER METAL
OUTER WALL
FRAME e.g. 1 1/2" x 1/4" GALV. M.S.
PIANO HINGE
PLASTER
WOOD FILLET EQUAL TO PLASTER DEPTH
HINGED FRAME e.g. 2 x 1 1/4" x 1/8" GALV. M.S. WITH MESH CLAMPED BETWEEN
DETAIL SHOWING METHOD OF OBTAINING CONTINUITY BETWEEN WALL AND WINDOW SCREENING

FIGURE 17. Window screens

Metal faced plywood

122. This can be used as a lining to walls, ceilings and floors or with suitable supporting structure can be used to construct a screened room or enclosure. Plywood $\frac{1}{4}$ in. thick, faced with 24 or 26 s.w.g. galvanised steel, is suitable for this purpose. Capping or angle strips or other means of jointing between sheets should preferably be of galvanised steel and so arranged that there is an intimate clamping contact throughout the length of the joints. Similar joints should be arranged between the sheets and door and window frames. Where screw fixings are used the spacing between screws should not exceed 18 in.

XI. Earthing

General

123. An extensive general electric conduit system will usually have a low d.c. resistance to earth, e.g. less than 1 ohm, but may have a much higher impedance to earth at high frequencies, and in these circumstances is liable to collect interference signals of sufficient magnitude to cause interference to sensitive apparatus. To prevent this it may be necessary to segregate the electric conduit in an interference-free area from the general conduit system of the hospital, by inserting a short electrically insulating section between the two systems at a convenient point just outside the interference-free zone. The segregated conduits should be connected to an independent earth-electrode, the connection being kept as short as possible and be metal clad throughout its length, e.g. 7/·029 in. cable in $\frac{3}{4}$ in. conduit. The metallic protection should be bonded to the independent earth electrode at the electrode end and the earthing connection taken to the earthing pins of all socket outlets in the segregated section.

Earth electrodes

124. The earth impedance necessary will depend on the degree of suppression required, but in general an impedance which satisfies the basic earthing requirements (No. 406) of the I.E.E. Regulations will be satisfactory.

125. The extent of the electrode system which will be required will depend on the soil resistivity. A typical electrode would consist of a steel cored copper rod $\frac{1}{2}$ in. in diameter and 8 ft. long. Where more than one rod is required the rods should be spaced apart by a distance at least equal to their length and connected in parallel.

126. Initially it is recommend that one electrode be installed and its earth impedance measured using an earth loop impedance test set*. Provided the rods are spaced apart as stated above, the overall impedance of an electrode system will be approximately equal to the measured impedance of one rod divided by the number of rods employed. In this way the number of rods required to achieve a specific impedance can be determined. The impedance of the final electrode system should be verified by testing, e.g. using an earth loop impedance tester.

Earth connections

127. Connections to earth electrodes should be made with a suitable clamp, e.g. a split or claw type non-zinc bronze connector with cable sweating socket.

128. Connections to earth electrodes and any buried or exposed part of the earthing conductor should be protected against corrosion by, for example, wrapping with an impregnated tape. Earth connections should be so arranged that they can readily be inspected and tested.

Multiple earth connections

129. Even where a special earthing system is used there is the possibility of small potential differences existing between separate earth connections, e.g. between different socket outlets in a room. Consequently where more than one mains operated monitoring unit is used on a patient at the same time, it may be found that one unit causes 50 c/s interference to the other. To eliminate this type of interference it will be necessary to use a common earthing point, e.g. by supplying both units from the same socket outlet using a multiple adaptor.†

Surgical diathermy

130. Some surgical diathermy sets incorporate an arrangement using an extra low voltage 50 c/s a.c. supply for continuously monitoring the plate electrode circuit, thus applying a small 50 c/s potential to the patient. This potential may obliterate any physiological monitoring record and in these instances it will be necessary to disconnect the plate electrode monitoring current before physiological recordings can be made.

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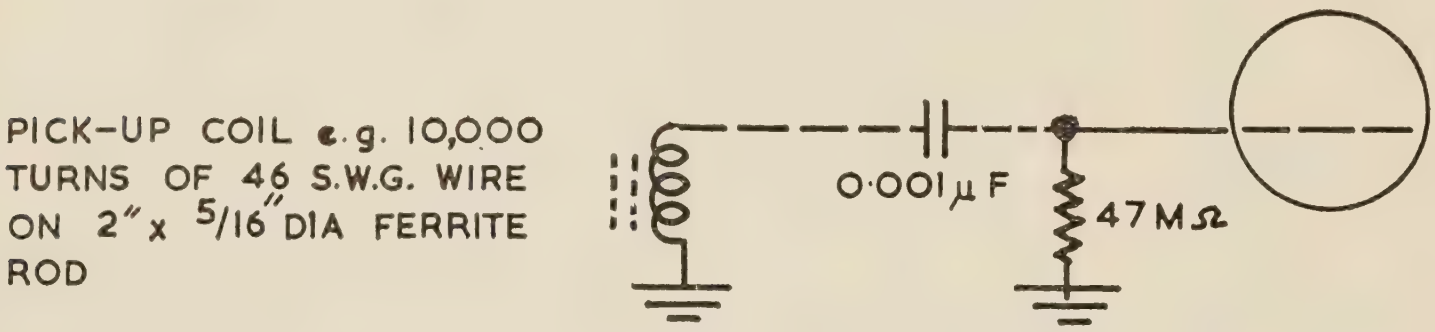
*The test measurement will include the impedance of the supply system earth but this will be small relative to the test value. Where long test leads are necessary a suitable allowance should be made for the resistivity of the leads.

†The use of multiple adaptors is recommended only where fused plugs are used.

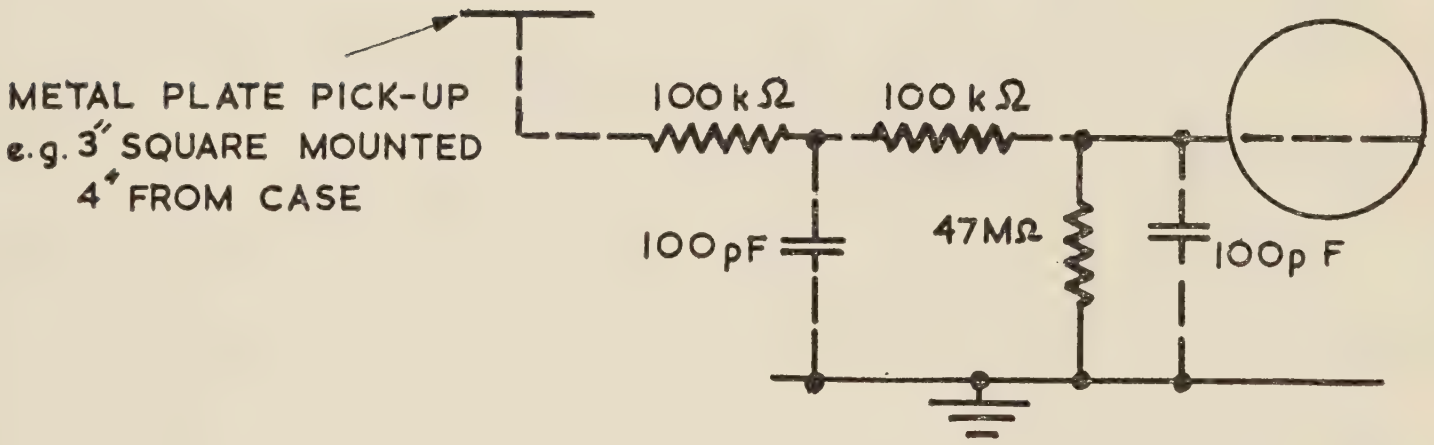
Appendix I

Detection of interference fields

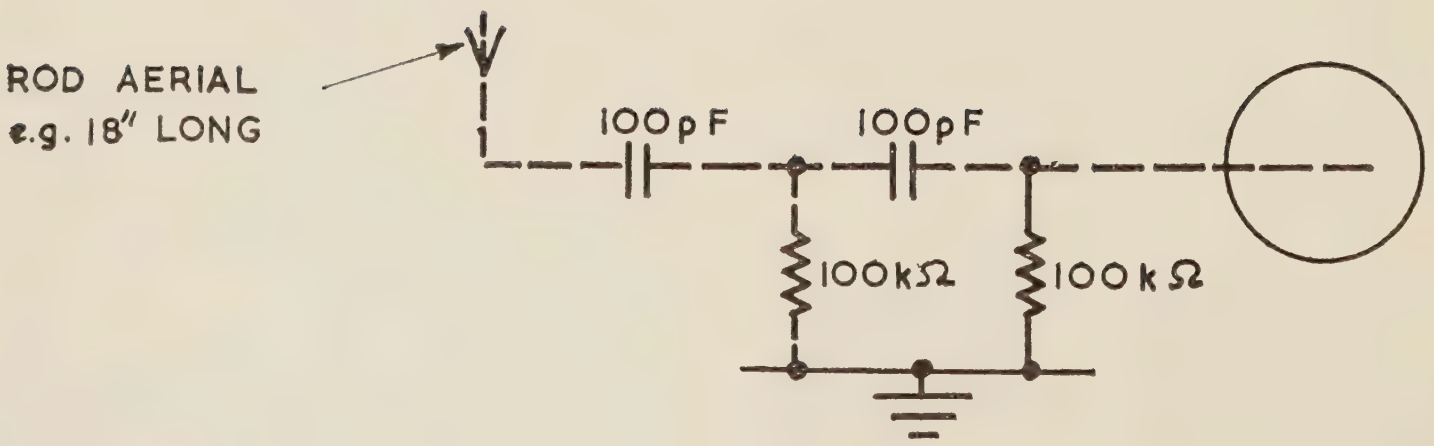
1. To enable remedial action to be taken against electrical interference, it is necessary to be able to detect the presence of the interfering signals and to determine the type of interference, i.e. whether it is due to high frequency radiation or to an alternating magnetic or electrostatic field. Sensitive physiological measuring apparatus can usually be used as a means of detecting interference but a small radio receiver or amplifier forms a much more convenient detector.



FOR DETECTING LOW FREQUENCY MAGNETIC FIELDS



FOR DETECTING LOW FREQUENCY ELECTROSTATIC FIELDS



FOR DETECTING RADIO FREQUENCY FIELDS

FIGURE 18. Modifications to valve operated hearing aids for detecting interference fields

2. *Radio frequency signals* can be detected on a radio receiver which can be tuned to the frequency of the signals. Interference signals which are due to arcing contacts are radiated over a very wide frequency band and can usually be detected anywhere on a medium wave-band receiver, but it is preferable that the receiver is not tuned to a known station.

3. High frequency radio receivers which are capable of being tuned to medical diathermy frequencies will not normally be readily available, but diathermy and other r.f. fields which are strong enough to affect sensitive electro-medical equipment can be detected on a high gain audio frequency amplifier such as a hearing aid, modified as shown in Figure 18.

4. *Alternating magnetic fields* such as may be due to transformers, chokes, stray currents in water pipes and structural metalwork, etc., can be detected using E.E.G. or E.C.G. apparatus with an appropriate pair of patient leads joined together to form a loop which can be used as a search coil.

5. A suitably modified audio-amplifier such as a hearing aid makes a more convenient detector for this type of interference. It will be necessary to connect a pick-up coil to the input of the amplifier. Figure 18 gives typical circuit details of the modification.

6. *Alternating electrostatic fields* can be detected by an audio-amplifier such as a valve operated hearing aid which has been modified by providing a capacitive probe connected via a low pass filter to the grid of the first valve of the amplifier. A typical circuit of the modification is shown in Figure 18.

7. The head box or the multi-way connector at the end of a screened patient cable connected to an E.E.G. machine can also be used to localise an alternating electrostatic field source.

Appendix 2

Screened rooms—materials and costs

Material	*Attenuation to be expected (db)*	*Cost (per sq. ft.)*	*Approx. cost installed (per sq. ft.)*	*Standard size sheet*	*Max. size sheet*
Galvanised steel $\frac{1}{8}$ in. × 24 s.w.g. (as Figure 12)	40–50	11d	8s. 0d.	4 ft. × 3 ft.	8 ft. × 3 ft.
Aluminium foil 0·0005 in. paper backed	50–60 (2 layers)	2d.	1s. 0d.	20 in. wide 6 or 12 yds.	20 in. × 50 yds.
Copper mesh $\frac{1}{4}$ in. × 20 s.w.g.	60–70	4s. 7d.	10s. 10d.	4 ft. × 3 ft.	8 ft. × 3 ft.
Copper foil 1 oz./sq. ft. (0·00135 in.)	80–100	7d.	1s. 6d.	3 ft. × 250 ft.	any width up to 52 in.
$\frac{1}{4}$ in. plywood with 24 s.w.g. galvanised steel facing	50–60	4s. 0d.	7s. 6d.	various	8 ft. × 3 ft.
Copper spray 0·004 in. on zinc bonding coat	60–70	—	from 9s. 6d. depending on location of hospital	—	—

The following are typical costs of other components for screened rooms:

Doors. $1\frac{3}{4}$ in. solid core door incorporating 0·012 in. copper foil at centre bonded on all sides to $\frac{1}{8}$ in. phosphor bronze edging. Door frame fitted with phosphor bronze contact strips at top and two sides. Total £55 per door.

Windows. Supply and fit two hinged window screens each 5 ft. 6 in. × 2 ft. 6 in. constructed with galvanised steel frames and $\frac{1}{8}$ in. galvanised steel mesh (as Figure 17). Total £40.

Mains filter. Supply and install 30A. mains filter. Total £40.

References

BRITISH STANDARDS INSTITUTION

B.S.613 Components and filter units for radio interference suppression.

B.S.729 Part 1: Zinc coatings on iron and steel articles.

B.S.800 Limits of radio interference.

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Statutory Instrument No. 291. The Wireless Telegraphy (Control of Interference from Electric Motors) Regulations 1955.

Statutory Instrument No. 292. The Wireless Telegraphy (Control of Interference from Refrigerators) Regulations 1955.

Statutory Instrument No. 1893. The Wireless Telegraphy (Control of Interference from Electro-Medical Apparatus) Regulations 1963.

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